Thesis/
Reports
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P.

PRELIMINARY LITERATURE REVIEWS

Fire Effects - Resource Output Modeling for Land Management Planning

CSU - NFFL

PRELIMINARY LITERATURE REVIEWS

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TABLE OF CONTENTS

FIRE DATA (Phil Omi) 1

FIRE BEHAVIOR/FIRE EFFECTS SUBSYSTEM (David Wheeler) 13

TIMBER SUBSYSTEM (Keith Paustian) 21

FORAGE SUBSYSTEM (Clint Wasser and Bob Gillen) 36

WILDLIFE SUBSYSTEM (Lee Rayburn) 67

HYDROLOGIC SUBSYSTEM (Phil Guertin) 80

RECREATION SUBSYSTEM (Michael Sieg and Perry Brown) 94

FIRE DATA

Phil Omi

HISTORICAL FIRE DATA

For purposes of this study, the concept of fire activity will be used to describe a set of variables or parameters which measure the ecological impact of fires in an area. Fire history provides an indication of fire activity for an area over time and also serves to provide estimates for inputs to be incorporated into the simulation model.

Upon viewing a map of historic fire occurrences, a complex pattern emerges. Fires vary with respect to size, intensity, location, and season of the year. Some fires may be caused by lightning; others are intentionally or accidentally set by man. Some vegetation types burn more frequently than others.

Reviews of time series data on fire activity for a given area reveal considerable variation in fire frequencies and sizes from year to year. There are many reasons for this variability, but fire weather factors are especially important. This variability suggests that fire activity should be handled probabilistically. Such an approach enables both mean and variance estimates to be incorporated into the simulation, provided certain assumptions are made concerning the distributional characteristics of the parameters of fire activity.

Estimable parameters of interest to this study may include:

1. acreage burned by location and cover type;
2. frequency and acreage burned by year;

3. frequency and acreage burned by size and intensity classes;

4. frequency and acreage burned by season by location.

The data for making these and other estimates for study areas in this project are contained in the Individual Fire Reports (Form 5100-29) of the U.S. Forest Service. Barrows (1951) utilized these forms in examining the fire history of the northern Rocky Mountains. The data base for his study has been expanded to the present and placed on magnetic tape at the CSU Computer Center by Barrows (in progress). Arno (1976) examined fire activity prior to the 1900s on the Bitterroot National Forest.

Fire history data for Colorado National Forests for the period 1946-1973 are also available at the CSU Computer Center. These data were analyzed by Ryan (1976). Clagg (1975) used historical information to examine the ecology and roles of fire in Colorado's high elevation forests.

The parameters of fire activity for an area may be estimated from these and other data sources for purposes of this project. Certain fire activity parameters have previously been assumed to follow the Poisson distribution (Davis, 1965; Kourtz, 1970; Heineke and Weissenberger, 1973). Harrison et al. (1972) utilized estimates for annual fire incidence, average fire size, and the recurrence interval between successive fires in a manner which made no assumptions with respect to underlying statistical distributions.

These approaches to generating fire activity parameters will be utilized in generating driving variables for the simulation model proposed for this study. It is important to note that some parameters of fire activity may not be generated by the fire effects model, per se. Where necessary, such inputs will be derived from historical data bases or from management interfaces, e.g., a manager will specify the size of a proposed prescribed burn.

The study of mechanisms involved in the propagation, shape, and size of individual fires is not within the scope of our project objectives, but is the subject of considerable past and ongoing research (Van Wagner, 1969; Rothermel, 1972; O'Regan, et al., 1973; Albini, 1976; Van Gelder, 1976; and others).

FUEL INVENTORY AND FLAMMABILITY DATA

Relationships between fuels and flammability are necessary ingredients for the fire effects simulation in our study areas. In nature, these relationships are often confounded by weather and topography, which interact with fuels to produce temporal and spatial variations in flammability. The study of fuel-flammability relationships has been facilitated by the following assumption: With the exception of dead fuel moisture contents, fuels react slowly enough with their surroundings to be considered static for any one fire (Countryman, 1972).

A fuel complex may be characterized by many parameters, including loading, shape, moisture, and chemical contents of fuel particles, as well as the compactness, continuity, and arrangement of the fuelbed. Under certain conditions, the properties of live fuels, duff, and litter must also be considered. Complete specification of all the descriptors of importance to fuel flammability is impractical, so fire researchers have necessarily focused on understanding fuel characteristics of an extent commensurate with the intended uses of the information. This has resulted in a spectrum of fuel and fire behavior models, some incorporating more detail than others.

Systematic analyses of fuels as they relate to fire behavior, have required the use of simplifying assumptions. For example, important fuel

descriptions are assumed to possess average or repeatable values throughout the fuels complex. One of the earliest attempts at fuel classification was by Show and Kotok (1930) who related fire behavior to pine cover types in California. Hornby (1936) systematized fuel conditions as related to expected spread rate and resistance-to-control indices in the northern Rocky Mountains. Barrows (1951) related the conditions within specific fuel types to spread factors observed on fires in the northern Rocky Mountains.

More recently, the concept of viewing wildland vegetation as fuel has been expounded by Countryman (1969), Fahnestock (1970), Muraro (1971), and Anderson (1974). Concurrently, several mathematical models have evolved which attempt to related physical-chemical properties of fuel descriptors to specific fire behavior, such as the forward rate of spread, flame length, and burning time. Several of the mathematical models incorporate measures of windspeed, slope, and fuel moisture influences. These modeling efforts have been summarized in Albini (1976).

Of particular interest to this project is the model presented by Rothermel (1972). As with any model, not all variables affecting fire behavior are included in the Rothermel model, and predictive accuracy in field applications will be constrained by inherent fuelbed homogeneity, continuity, and uniformity assumptions. Nevertheless, the model has been tested or applied in several field applications (Brown, 1972; Lindemuth and Davis, 1973; Rothermel and Philpot, 1973; Van Gelder, 1976; Sneeuwjagt and Frandsen, 1977), and functions reasonably enough to be used in the National Fire Danger Rating System (Deeming et al., 1977).

Fuels in the Rothermel model are specified by fuel particle and fuel array properties, by categories of fuel type and size class. Ideally, comprehensive fuel inventory information (including values for fuel particle

density, heat and mineral contents) would facilitate the prediction of fire behavior parameters for all fuel complexes of interest. Roussopoulos and Johnson (1975) utilized such an approach for slash conditions and weather regimes applicable to the northeastern U.S. However, such an approach is generally infeasible due to the inherent variability of wildland fuels and high sampling costs involved. For example, techniques developed for estimating fuel loadings (Van Wagner, 1969; Brown, 1974) may be costly, time-consuming, and tedious.

The task of relating fuels to flammability has been simplified through the notion of stylized fuel models, selected to represent typical field situations. The Rothermel model may be utilized to calculate measure of rate of spread and fire intensity in stylized fuel models (Albini, 1976). The Rothermel model is also used to indicate fire potential in the 20 fuel models of the National Fire Danger Rating System (NFDRS). The necessary computations and input values are embodied in computer programs and data banks accessible on the CDC 7600 at the Lawrence Berkeley Lab Computer Center.

The outputs from NFDRS computations can be used to approximate measures of potential fire behavior within a given fuel model, under varying slope and weather conditions. For example, the spread component of the NFDRS is numerically equivalent to the theoretical spread rate (ft/min) of an initiating fire. The energy release component is equal to the available energy (Btu/ft^2) divided by 25. The burning index is scaled to 10 times the predicted flame length (ft).

Other flammability indicators retrievable from the NFDRS routines include the reaction time, τ(min). In terms of the surface area to volume

ratio, σ,

$$\tau = \frac{384}{\sigma}$$

where σ is weighted by the surface area of the fuel size classes within the fuel complex (personal communications with Jack Cohen). If weighted by the loadings of fuel size classes, the expression $\frac{384}{\sigma}$ may be useful as a surrogate for residence time of the fire front (personal communication with Frank Albini).

The use of default parameters inherent to stylized fuel models limit the predictive capability associated with the resultant outputs. At the same time, the less stringent data requirements of stylized fuel models are compatible with aims and resources of this project. Such an approach presumably will enable comparisons of fuel-flammability relations in fuel complexes separated by time and space.

It is likely that the 20 fuel models of the NFDRS will insufficiently specify the range of fuel complexes of relevance to this study. In such cases, we will rely on existing literature and inventory information to provide estimates for the required inputs. For instance, fuel loadings of residues from logging have been estimated for northern Rocky Mountains by Benson and Johnston (1976). Pierce (1977) computerized a data bank for natural fuels in western coniferous forests. Brown and Marsden (1976) estimated fuel weights of grasses, forbs, and small woody plants common to western Montana and northern Idaho. Brown (1976) developed regression equations for estimating shrub biomass in the northern Rocky Mountains. Clagg (1975) and Rowdabaugh (in progress) have inventoried fuels in high elevation forests of Colorado. The list of studies, though far from complete, will be updated in the preliminary stages of this project. Information

from these studies will be supplemented by fuels data supplied by National Forests within the project study areas.

FIRE WEATHER AND FIRE DANGER RATING DATA

Weather produces the greatest variations in fire activity in an area. While forest fuels possess an innate potential for fire spread and intensity during a given time period, weather conditions regulate both instantaneous and long-term fluctuations in fire potential.

Fire weather is defined as weather conditions which influence fire starts, fire behavior, or fire control (Brown and Davis, 1973). Micrometerology and its interactions with forest cover and topography are covered in Schroeder and Buck (1970). Broader scale or synoptic influences are treated by Schroeder (1964) for the continental United States. He identified synoptic patterns associated with critical fire weather within different regions of the country, including the northern and southern Rocky Mountains. Cohen (1976) analyzed mountain fire weather in Colorado in terms of relationships between dry-wind conditions and critical fire weather.

Most fire weather studies have relied upon existing and past ratings of fire danger, such as the burning index (BI) of the National Fire Danger Rating System (Deeming et al., 1977). Daily weather observations collected at field stations throughout the United States are processed into the AFFIRMS system (Helfman, et al., 1975) for calculating fire danger ratings. At regular intervals, observations and fire danger ratings are entered into the FIRDAT library (Furman and Brink, 1975) for permanent storage on the Univac 1108 at the Fort Collins Computer Center.

There are two needs for fire weather information on this project:

1) to control for variations in fire behavior induced by weather conditions in the fire whose effects are being studied; 2) to establish a range of plausible weather situations for use in the computer simulations.

These needs may be met through a combination of data sources. With respect to #1, it may be possible to reconstruct the desired fire weather conditions by existing literature of fire records. The fire weather on more recent fires may also be approximated by accessing the FIRDAT library with the appropriate fuel model and slope class. Yet another data source exists in the Daily Weather Maps of the U.S. Department of Commerce.

The need for precise fire weather information for the computer simulations (need #2) is less critical insofar as we are not interested in the propagation mechanisms governing fire spread. This does not mean that we will neglect the possible influence of different weather regimes on simulated fires. The range and impacts of plausible weather regimes should be apparent from the analysis of data for need #1, and from management interfaces.

FIRE EFFECTS DATA

An understanding and appreciation for the complexity of forest fire effects is essential to effective forest management. The wide range of effects due to forest fires encompass physical, chemical, biological, and social impacts. These effects may be immediate and readily visible, or they may be delayed and undetected.

Fire effects have been conveniently grouped by impacts on trees, shrubs, herbs, microclimate, and soils (Brown and Davis, 1973). Heat effects on living plants have been summarized by Hare (1961). Kittredge (1948) compiled information on short- and long-term relations between fire and the

vegetative, microclimatic, water, and soil systems. These and other references provide extensive literature lists from which pertinent source material may be drawn. In addition, the FIRBASE information system (Taylor, 1975) provides a computerized literature search of publications relevant to fire management.

It is unfortunate that most fire ecology studies lack information on fire behavior or fire potential, while fire behavior studies generally neglect consideration of ecosystem impact. For these reasons, not all fire studies will be of use to this project. Those studies of relevance to this project will be denoted as elements of the fire effects data set, consisting of fires identified in the literature review as possessing sufficient information to enable parameterization of key fire behavior indicators and fire effects. The effects of interest are those which provide restart conditions and controls for the timber, forage, wildlife, watershed, and recreation submodels. Therefore, the project investigators with responsibility for these resource models will be relied upon to provide the necessary information sources for establishing the required fire behavior-fire effects relationships.

The construction of these relationships will be facilitated through the stylized fuel model approach taken in this study. The fire effects data set will consist of those literature fires which, at the very least, provide sufficient information to enable specification of the appropriate fuel model and the variables operating within the fire environment.

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FIRE BEHAVIOR/FIRE EFFECTS SUBSYSTEM

David Wheeler

INTRODUCTION

This general literature review attempts to include portions of the literature necessary to establish the inputs required for the subsystem and to establish the linkage of fire effects to fire behavior.

The major inputs required for this project will be determined by fire history studies; by the National Fire-Danger Rating System (Deeming et al., 1977); and by fire behavior models as described by Albini (1976). The strategy behind relating fire behavior to fire effects will rest upon the feasibility of acquiring the behavior characteristics and abitic conditions of specific fires and matching those parameters with the effects, both short-term and long-term, of the fires. The above combinations of data are rare. Generally the fire data available covers only the behavior and abiotic conditions of a specific fire, such as Anderson's (1968) analysis of the Sundance Fire; or the general ecological effects of fire (Ahlgren and Ahlgren, 1960; Kozlowski and Ahlgren, 1974). Extrapolation of the existing data to fires without complete data records will supplement the information base.

FIRE HISTORY DATA

For purposes of this study, the concept of fire activity will be used to describe a set of variables or parameters which measure the ecological impact of fires in an area. Fire history provides an indication

of fire activity for an area over time and also serves to provide estimates for inputs to be incorporated into the simulation model. The parameters of interest derived from the fire history analysis will include size class; intensity; topographical characteristics, i.e., slope and aspect; season; and ignition source frequencies by habitat types on an annual basis. Probablistic prediction of future fire activity can then be made.

The procedure required to obtain such information involves studying the pattern of fire history for each habitat of interest. These and other estimates for study areas in this project can be made from the Individual Fire Reports (Form 5100-29) of the U.S. Forest Service. Barrows (1951) utilized these forms in examining the fire history of the northern Rocky Mountains. The data base for his study has been expanded to the present and placed on magnetic tape at the CSU Computer Center by Barrows (in progress). Additional studies of fire history in the northern Rocky Mountains include Wellner (1970), Habeck and Mutch (1973), and Arno (in progress).

Fire activity data for Colorado National Forests for the period 1946-1973 are also available at the CSU Computer Center. These data were analyzed by Ryan (1976). Clagg (1975) assembled fire history data for Rocky Mountain National Park and Roosevelt National Forest from National Park Service and U.S. Forest Service records. The history of fire prior to 1900 in the Bitterroot National Forest is addressed by Arno (1976).

MODEL INPUTS

The NFDRS (Deeming et al., 1977) will be the basic ingredient used to drive the fire behavior submodel. The rating system is a tool used

to predict the risk of a fire ignition, both man-caused and lightning-caused, and the degree of fire hazard for management planning on a day-to-day basis (Albini, 1976). Further behavior characteristics will be furnished by Rothermel (1972).

The NFDRS and Rothermel's fire spread model, are functions of several broad groups of inputs: location, weather, use, and fuels. Most can be easily determined. The location and weather inputs will be considered in the linkage section of this review. The weekly cycle of use trends will be defined by the resource use data provided by the land manager and the NFDRS guidelines. However, the fuel-related inputs, in particular fuel loadings with respect to the timelag moisture classes (Lancaster, 1970), are especially elusive considerations because of the dynamic structure of the forest.

FUEL-RELATED INPUTS

Several studies have made estimates of crown biomass production at a given point in time. Kittredge (1944) made measurements of needle weight per tree based on the periodic annual increment of dbh, basal area, or volume. His work showed that site quality and age may have an additional affect on the regression equation for each species, but that apparently crown class and density distribution does not. Brown (1976) estimated slash branchwood by size classes in predicting the total crown weight for several economically important Rocky Mountain species. Other relationships concerning total crown weight have been made with respect to species tolerance, slash moisture content, and fire spread potential (Fahnestock, 1960). These relations are useful in estimating the increase in fuel loading due to cutting operations or road construction, i.e., distance events.

The continuous process of growth and mortality is the major source of fuel build-ups (Dell and Wilson, 1971). The climate existing in the northern Rocky Mountains permits annual biomass production to exceed annual decomosition (Brackebusch, 1973; Norum, 1976) creating a net accumulation of fuels. Some work has been done to determine the rate of accumulation. Annual needle and cone drop, branch breakage, and live tree and snag blowdown are important considerations in answering the question of fuel accumulation rates.

Pierce (1977) developed a series of regression models with fuel loading as the dependent variable and stand age as the independent variable. The conclusion that can be drawn from his results is that either there is no relation between fuel loading and stand age, or that more independent variables are to be considered than just stand age. Another study (Clagg, 1975) although, produced accumulation rates and fuel characteristics of spruce-fir and lodgepole pine vegetation types found in Rocky Mountain National Park and adjacent Roosevelt National Forest. Definite correlations of stand age to woody fuels (1000-hour, both sound and rotten, 100-hour, and 10-hour timelag classes), number of snags, and duff/litter depth were found. Additional correlations of basal area, crown closure, and aspect were also addressed.

Fuel loadings at given times can be found in the quantitative data available concerning downed woody material, litter, and humus biomass for different aged Douglas-fir stands of similar site quality in western Washington (Turner and Long, 1975). These researchers have also produced estimates of the above-ground biomass in terms of understory and overstory live fuel complexes (Turner and Long, 1975). Habeck (1976) presents

averaged fuel loadings of five community tyes, represented by 18 stand groupings found in the Selway-Bitterroot Wilderness.

BEHAVIOR/EFFECTS LINKAGE

Behavior weather produces the greatest variations in fire activity in an area. While forest fuels possess an innate potential for fire spread and intensity during a given time period, weather conditions regulate both instantaneous and long-term fluctuations in fire potential.

Fire weather is defined as weather conditions which influence fire starts, fire behavior, or fire control (Brown and Davis, 1973). There are two needs for fire weather information on this project: 1. to control for variations in fire behavior induced by weather conditions in the fire whose effects are being studied; 2. to establish a range of plausible weather situations for use in the computer simulations.

These needs may be met through a combination of data sources. Most fire weather studies have relied upon existing and past ratings of fire danger, such as the burning index (BI) of the National Fire Danger Rating System (Deeming et al., 1977). Daily weather observations collected at field stations throughout the United States are processed into the AFFIRMS system (Helfman et al., 1975) for calculating fire danger ratings. At regular intervals, observations and fire danger ratings are entered into the FIRDAT library (Furman and Brink, 1975) for permanent storage on the Univac 1108 at the Fort Collins Computer Center.

By accessing the FIRDAT library with the appropriate fuel model and slope class the fire weather conditions of recent fires can be approximated. Conditions can also be reconstructed from existing literature

of fire records. Yet another data source exits in the Daily Weather Maps of the U.S. Department of Commerce. Analysis of the above data sources coupled with management interfaces, will provide the range and impacts of plausible weather regimes to be used on simulated fires.

Besides the slope class designation already mentioned, the aspect of the site will be necessary to give a sufficient description of the fire location topography.

EFFECTS

As stated above, most fire ecology studies lack information on fire behavior or fire potential, while fire behavior studies generally neglect consideration of ecosystem impact. For these reasons, not all fire studies will be of use to this project. Those studies of relevance to this project will be denoted as elements of the fire effects data set, consisting of fires identified in the literature review as possessing sufficient information to enable parameterization of key fire behavior indicators and fire effects. The effects of interest are those which provide restart conditions and controls for the timber, forage, wildlife, watershed, and recreation submodels. In addition, the possibility of initiating new fires with new behavior conditions will be considered. Therefore, the project investigators with responsibility for these resource models will be relied upon to provide the necessary information sources for establishing the required fire behavior-fire effects relationships.

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TIMBER SUBSYSTEM

Keith Paustian

This review is intended to give an overview of some of the general literature on fire effects which will be considered in building the timber submodel. It is not intended to be exhaustive, but merely to present some examples of previous research in areas pertinent to fire effects, due to both wildfire and prescribed fire, on the timber resource of the forest ecosystem.

Fire has long been recognized as being one of the major ecological factors influencing the development of the coniferous forests, not only in North America, but in much of the temperate regions of the world (Brown and Davis, 1973; Uggla, 1974; Crane, 1972). Scotter (1972) refers to the North American boreal forest as a "disturbance" forest where the patchwork mozaic of timber types is best explained by the influence of fire.

Working in the coniferous forests of north central United States, Maissurow (1935) reports the occurrence of charcoal in 95 percent of the forested area, indicating the past presence of fire throughout the region. Heinselman (1971) reports that in forests of the Boundary Waters Canoe Area of Minnesota, charcoal in the soil organic layers is present throughout the area, and that tree ring analysis showed that fires occurred with a frequency of between five and forty years from 1600 A.D. to the present. Studies of bog depositions ranging from 3,000 - 8,000 years in age and the recovery of 38,000 year old tree fossils of

jack pine and black spruce (both typical fire species) in Minnesota, further attest to the length of time in which fire has been associated with the coniferous forest ecosystem (Heinselman, 1971). In general, fire has been found to affect the structure, composition, and in some cases the very existence of, such diverse forest types as the jack pine, black spruce and aspen stands of north central United States, the pine-hardwood forest of New Jersey, the coastal plain pine forests of the southeast, the ponderosa pine areas in the Pacific west and the southwestern United States, the Douglas-fir forests of the northwest, and the lodgepole pine areas of the Rocky Mountains (Horten, 1956; Huberman, 1935; Munter, 1940; Mogren and Striffler, 1971; and Weaver, 1955).

In modeling fire effects on the timber resource, it is necessary to consider how fire influences the growth and yield, reproduction and fuel accumulation of forest stands. For the purposes of this review, impacts of fire will be divided as to "direct" effects and "indirect" effects on the timber resource. It is realized that this is a highly artificial division considering the complexity of the interrelationships involved in tree responses to fire, but it is believed that it will be useful in organizing the material.

DIRECT AFFECTS

Tree Mortality

The most extreme effect of fire on a timber species is the destruction of the living tissues to the extent that the tree is killed. Hare (1961) gives a thorough treatment of the effects of heat, due to

fire, on the various plant tissues. He lists such factors as season, species, insulation, age and size as having an influence on how trees respond to heat injury due to fire. It is generally considered that a temperature of the tree of 140°F is lethal to most plant tissues (Albini, 1976), and that death can result when tissue damage is severe enough, such as with complete crown or cambial kill (Hare 1961). One of the early workers concerned with general tree resistance to fire and fire mortality was Flint (1925) who related fire resistance to bark thickness, root habits, resin content of bark, branching habit, stand habit, relative flammibility of foliage, and amount of lichen growth. Starker (1934) developed a similar ranking for tree species of the Northwest, by considering many of the same factors.

Recent efforts in studying tree mortality due to fire have been directed toward the importance of bark as a protective mechanism and the influence of crown scorch on tree survival. Spalt and Reifsnyder (1962) have prepared an extensive review of the literature pertaining to bark and fire resistance. Included is a discussion of various physical properties of bark such as: thickness, thermal conductivity, heat capacity, thermal diffusity, density, and moisture, as they relate to heat transfer and insulation. Vines (1968) found that fire resistance in Eucalyptus was closely related to bark thickness and that only older thick-barked trees could be expected to survive severe fires. Bark thickness was found to explain part of the variability in seedling survival of slash pine in Florida in a study conducted by McMinn (1967). However other characteristics than bark thickness, such as percent of outer bark present, have been found to be of importance in fire resistance (Stickel, 1941). Langdon (1971)

found that when bark thickness was held constant, long leaf and slash pine proved to be twice as resistant to heat injury as sweetgum, cherry and holly.

In summary, bark thickness generally appears to be the most important tree characteristic influencing the amount of cambial kill resulting from a fire. However, other bark characteristics must be considered as factors affecting mortality, and these will be treated in the model as being functions primarily of tree species, size, and age.

Amounts of crown scorch resulting from fire has been shown to be important as a cause of tree mortality. Norum (1977) reported that Douglas-fir in Montana had little chance of surviving scorches of greater than 60 percent, although western larch and ponderosa pine were able to tolerate somewhat higher scorch amounts. In a prescribed fire in ponderosa pine, Morris (1958) found that 51 percent of the trees killed had 95 to 100 percent of their crowns scorched. Hermann (1954) and Wagener (1961) provide guidelines on probable tree mortality following fire, in which crown scorch is a principle component. Crown scorch has been found to be closely related to Byram's fireline intensity by Van Wagner (1973) and methods for calculation are presented by Albini (1976).

Tree mortality due to fire have been documented in several case studies. McNab (1977) found that a low intensity fire (I=23 Btu/ft-sec) in loblolly pine acted as a thinning from below, where mortality was directly related to tree diameter at ground line. Cambell et al. (1977) compared two wildfires in ponderosa pine and found that 50 percent of trees eight inches or less in diameter and 7 percent of the trees eight inches or greater were killed in a moderately intense burn, while in a severe burn, 90

percent of trees less than eight inches and 50 percent greater than eight inches, were killed. A prescribed fire, studied by Ffolliot et al. (1977) in ponderosa pine showed a decrease in basal area of 47 percent where average tree diameter was six to eight inches and fire intensity was 48 Btu/ft-sec., and a decrease in basal area of 25 percent where average diameter was 12 to 14 inches and fire intensity was 90 Btu/ft-sec. Several other researches have reported fire-caused mortality in relation to tree and fire characteristics (Bruce, 1954; Gaines et al., 1958; Little and Moore, 1945; Loomis, 1977; and Pearson et al., 1972).

Growth

Individual tree growth and thereby overall stand yield can be affected by a fire event. Obviously damage induced by fire can result in reduced tree vigor and therefore reduced growth, depending on the severity of the injury. Several studies have been made relating loss of growth following reduction of the trees' photosynthetic area by pruning (Dahms, 1954; Mogren, 1967). Crown reduction due to scorch might be expected to have similar effects on growth. However, detrimental effects of fire on tree growth need not always be the case. Both Bruce (1951) and Maple (1977) observed increases in height growth of longleaf pine seedings following prescribed fire. The relative increase in height growth of longleaf seedlings was found by Grelen (1975) to be greater on areas prescribed burned in May than on those that were burned in March or July. Langdon (1971) reported that growth of pine saplings decreased where considerable crown scorch occurred in conjunction with prescribed burning in the southeastern coastal plain, but that trees with little crown scorch

showed no loss in height or diameter growth. In using prescribed fire for thinning overstocked ponderosa pine, Morris and Mowat (1958) found that diameter growth increased an average of 35 percent and height growth 7 percent for selected crop trees with little scorch damage, primarily because of the removal of competitors. The same study revealed that diameter growth suffered little even with considerable crown scorch, while height growth was more adversely affected.

Regeneration

An understanding of forest regeneration reponses to fire is necessary in order to model future stand development after a wildfire or prescribed burn. The impact of fire on seed availability after fire has been studied in many investigations, and is a key consideration. Ahlgren (1959) emphasized the importance of cone serotiny in jack pine and partial cone serotiny in black spruce for successful regeneration of these species after fire. According to Algren (1959) fire also acted in stimulating germination of jack pine seeds. Cone serotiny is a well known phenomenon in lodgepole pine stands, whereby mature lodgepole pine stands may contain millions of stored seeds per acre which can be released after fire (Lotan and Baumgartner, 1975). Lotan and Baumgartner (1975) found considerable variation in the occurrence of serotinous cones in lodgepole stands, throughout its range. Stands with predominantly serotinous cone character were found in one instance by Boe (1956) to have better regeneration following clearcutting on unburned plots than on burned plots, because most of the stored seed in the slash was destroyed by burning.

Fire can influence seedling establishment through its effect on the seedbed and the surrounding microclimate. Jack pine establishment as studied by Algren (1959) and Cayford (1970) was made possible by burnoff of duff resulting in a mineral soil seedbed. Shearer (1976) found that prescribed burning in the summer or fall provided more receptive seedbeds in western larch and Douglas-fir stands in Montana. Bruce and Bickford (1950) reports that prescribed fire improves "seed catch" and results in increased survival in longleaf pine seedlings. Broadcast burning in mixed conifers on the Klamath National Forest, as reported by Heavilin (1977), resulted in poorer regeneration than on adjacent unburned plots. This was attributed to three factors: the establishment of a root pathogen was enhanced on the burned areas, slash on the unburned areas provided needed shade for seedlings, and nutrient loss following burning was substantial due to the course textured soil present. Toxic amounts of minerals present in the ashbed following fire were found by Algren (1959) to inhibit seedling establishment for one to two years after fire.

INDIRECT AFFECTS

Soil and Site

Changes in soil and site characteristics due to fire can be considered as indirect effects of fire on the timber resource. Important changes on forest soils following fire often include an initial increase in pH and available cations and a substantial decrease in total nitrogen (Baker, 1968; Uggla,1974; Viro, 1974). Uggla (1974) reports increases in the growth of Scotspine following planting of a burned site, due to the favorable changes in the humus layer. Similarly, growth of planted

pine in Norway was increased by prescribed burning after harvest on the poorer sites, but growth on the better sites was slower on the burned plots as compared to the unburned (Braathe, 1974). In broadcast burning under western larch-Douglas-fir stands, Steele (1976) found nutrient availability increased as a function of fire intensity, but that no increase in growth was associated with this.

Insect and Disease

Considerable research has been done on the relationship of fire to the incidence of disease and insect attack in forest stands. The occurrence and severity of insect and disease attacks are influenced by fire and in turn, insect and disease outbreaks are in some instances related to the fuel build-up and therefore fire potential of an area. Wildfire is a major factor governing the distribution and abundance of dwarf mistletoe according to Alexander and Hawksworth (1975). Furniss (1965), has found that the susceptability of trees to bark beetle injury is enhanced by fire damage, and that the incidence of attack increases with the size of the tree and the amount of crown and cambial injury involved. Stickel (1940) reports that basal wounds or "fire scars" caused by fire often give a mode of entry into the tree for insects and pathogens, which can result in greatly increased mortality and growth losses following fire in eastern hardwoods. Insect attacks which kill large numbers of standing trees, are described by Balch (1942) and Flieger (1970) as being responsible for increased fuel accumulation in northern coniferous forests resulting in increased fire hazards. On the other hand, fire can have a beneficial effect by controlling disease such as brown spot needle blight

(Bruce, 1954; Langdon, 1971), or in the irradication of dwarf mistletoe infested stands (Wilker and Leaphart, 1976).

Competition

The importance of fire in maintaining the structure and composition of ponderosa pine in certain areas of the western United States has been pointed out by Weaver (1955) and Biswell (1973) who maintain that the invasion of more shade tolerant species is, in many cases, prevented by the frequent, natural occurrence of fire. Kilgore (1973) discusses the importance of fire in limiting the succession of tolerant understory species in the sequoia-mixed forests of California. Controlled burning aided in the reduction of hardwood competition from a New Jesey pine hardwood stand (Little and Moore, 1945).

Fuel accumulation through time for the different fuel models will be handled jointly by the fire and timber submodels. A discussion of literature pertinent to this area is included in the fire submodel review. In addition, a brief discussion of some general interrelationships between forest fuels and fire effects on the timber resource is included here. Fire can result in both decreases and increases in forest fuel accumulation which in turn affects fire characteristics important to the timber submodel. Weaver (1955) and Biswell (1973) believed that frequent natural fires in ponderosa pine resulted in low fuel accumulations and therefore predominantly surface fires of low intensity occurred. In a prescribed burn in ponderosa pine, three fourths of the surface fuels were removed, successfully reducing fire hazard (Ffolliot et al., 1977).

In larch Douglas-fir stands in Montana, prescribed burning (termed BUST burning) is being used for fuel reduction understanding timber according to Stark (1976). Gaines et al. (1950), found that a light fire in September resulted in a fuel reduction of 45 percent in the stand, while a more intense fire in October causes a ninefold increase in standing dead fuels. Brown and Davis (1973) sum up the problem of fuel reduction as being a primary goal of prescribed burning in most of the areas where fire is used as a silvicultural tool.

SUMMARY

Fire is one of the major ecological factors responsible for the distribution, structure, and composition of many of the major coniferous forest types of North America. In considering fire effects on the timber resource from the modeling point of view, both "direct" and "indirect" effects are recognized. The "direct" effects of fire on tree species include: mortality, effects on growth and development, and effects on forest regeneration. "Indirect" effects of a fire on the timber resource include: effects on soil and site characteristics, the relationship between insect and disease and fire, the effect of fire on vegetation competition, and the interrelationship between forest fuels and fire.

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FORAGE SUBSYSTEM

Clint Wasser and Bob Gillen

THE PROBLEM

Lyon (1966) has pointed up the habitat management problems for big game in the northern Rocky Mountain forests. Disastrous wildfires after 1900 have caused forests to be replaced by shrubs and spawned an explosive expansion of big game populations. More recently, forest regeneration has resulted in a deterioration of the wildlife environment except where shrubs are being maintained locally as unplanned by-products of logging.

GENERAL SOURCES

Wright (1974) has reviewed and summarized salient features about the use of fire as a tool in range and forest resource management, the effects of fire on vegetation and wildlife, and techniques for burning. He called attention to the feasibility of using fire to control undesirable vegetation and encouraged desirable cover types by knowledge of fire ecology and technology. The possible use of fire in forests to improve wildlife habitats and control liver fluke and lungworms, and the salutary effects of fire upon shrubs in the Douglas-fir zone of the Intermountain Region, in particular, were pointed out.

Ahlgren and Ahlgren (1960) have published a comprehensive review regarding the effects of fire upon forest vegetation. A similar review of effects of fire upon grasslands has been prepared by Daubenmire

(1968). General background information concerning effects of fires upon soils, nutrients, moisture, temperature, and many other ecological parameters of forests and grasslands are found there.

HABITAT TYPES

Daubenmire (1968) proposed that habitat types are ecosystems that could be mapped and used in vegetation classification. The Daubenmires (1968, 1970) classified the forest and steppe regions of Washington and adjacent Idaho according to habitat types. Pfister (1976) showed the utility of habitat type classification to the problem of land capability assessment. Recently Pfister et al. (1977) developed the monograph: The Forest Habitat Types of Montana. Figure 50 of the latter describes an elevational gradient of communities somewhat similar to those found in adjacent Bitterroot Mountains.

In adapting Daubenmire's system to fit ECOCLASS, a U.S. Forest Service classification scheme (Corliss and Pfister, 1973), areas dominated or potentially dominated by climax forest species, e.g., ponderosa pine, Douglas-fir, grand fir, and subalpine fir are each termed SERIES, and when linked with undercover dominants such as bluebunch wheatgrass, Idaho fescue, pine reedgrass, common snowberry, ninebark, vaccinium, twinflower, queencup cornlily, beargrass, menziesia, and Hitchcock woodrush form habitat types. A third dominant or a second undercover codominant are termed phases. Table 1 (see appendix) lists 48 habitat types/phases sampled by Pfister et al. (1977) on the Bitterroot National Forest.

The southern Rocky Mountains and the Arapaho-Roosevelt National Forest are incompletely covered by habitat type classifications or maps. Wirsing and Alexander (1975) have developed preliminary habitat-type classifications and descriptions of forest communities on the Medicine Bow National Forest which borders the Roosevelt National Forest. Steen and Dix (1974) have prepared a preliminary community classification outline and key for the subalpine forests of Colorado. Whipple (1975) has prepared a slightly different landscape and community classification for the Fraser Experimental Forest in the Arapaho National Forest. Marr (1961) has prepared an ecosystem classification for the elevational gradient of forests found near Ward, Colorado on the Roosevelt National Forest.

FIRE SUCCESSIONS

Larsen (1929) has outlined vegetation and stages that characterize postfire successions in the forest zones of the Bitterroot Mountains of northern Idaho. He has also characterized the site conditions which favor the respective forest trees (Larsen, 1940). Mueggler (1965) monographed the plant succession, species, and group interrelations with site factors after fire and other disturbances in the Bitterroot-Selway regions of Idaho.

Basile and Jensen (1971) developed a post-clear-cutting and burning successional curve for east-side Montana lodgepole pine in which forage production is shown for sedges, grasses, forbs, and shrubs for 17 years. It is similar to Lyon's and the Region 1 Wildlife Handbook successional production curves discussed later.

Tiedemann and Klock (1973) noted that first year vegetation after fire, on the Entiat Experimental Forest in Washington in lodegpole and Douglas-fir forests, was largely certain fire resistant members previously present, notably bracken fern, spreading dogbane, and fireweed. Pine reedgrass and Ross sedge were frequent; sprouting shrubs such as snowbrush ceanothus, willow, and alder were prominent, while birchleaf spiraea was a prominent half-shrub. Fire-induced germination of ceanothus seeds produced from five to ten seedlings per meter square. It was the dominant shrub.

FIRE SUCCESSIONAL STAGES, GROUPINGS, AND COMPOSITION

Larsen (1929) lists the climax and successional vegetation for the Bitterroot Mountains of northern Idaho. Mountains extend to 6,000 or 8,000 feet from valleys of 2,000 or 3,000 feet elevation. Pinus ponderosa (ponderosa pine) occupies lowest zones of the forest; Pinus monticola (white pine), Thuja plicata (white redcedar), Thuja plicata (western redcedar), Tsuga heterophylla (western hemlock), Abies grandis (grand fir), Pseudotsuga menziesii (Douglas-fir), and Larix occidentalis (western larch) occupy slopes of intermediate elevation (2500-5500'); and Picea engelmannii (Engelmann spruce), Tsuga mertensiana (mountain hemlock), Pinus albicaulis (whitebark pine), Abies lasiocarpa (subalpine fir), Pinus contorta (lodgepole pine), constitue the subalpine forest. The intermediate zone has Tsuga, Thuja, and Abies as climax but is called the white pine zone. Lodgepole pine is also often found in this zone.

Succession on small areas after fire return rapidly to trees: first, lodgepole pine on dry, eroded, gravelly sites; larch may also persist due to fire-resistance, thicker bark, and longevity. In the absence of repeated fire, western whitepine and Douglas-fir will establish under lodgepole and western larch and crowd them out in the second stage. As these trees mature and prevent Douglas-fir and lodgepole reproduction from becoming established, climax species, western hemlock, western redcedar and grand fir, begin underseeding.

Succession of subordinate vegetation is outlined as follows: The first stage is composed mostly of herbs, most of which are broadleaved forbs. Larsen lists 11 species in this category.

The second stage develops in two or three years. Most species are perennials and have berry fruit spreading by birds but may exist as seedlings in the early succession. Most are shrubs, 21 species are enumerated for this stage.

Larsen noted that a second burn at this stage often induces stands of Ceanothus velutinus and C. sanguineus on dry south slopes. After eight to ten years, tree seedlings begin to overtop and shade out ground cover, only maple persists for 50-60 years, and pave the way for the third set of subordinates. Some 25 taxa are listed here with a few site reference notes. Increasing shade tolerance but variable moisture demands characterize this set. Subordinate species are listed in Table 2 (in appendix) with brief ecologic notes.

Larsen notes that at about the same time as climax species appear the climax subordinates appears. Most of these species, of the 14 taxa listed, are either intermediate or quite shade tolerant and either forbs or lower shrubs. See Table 2 (in appendix) for species listings.

Mueggler (1965) monographed the ecology of seral shrub communities in the cedar-hemlock zone of northern Idaho. Closed forest communities and environmental relations are compared with logged and burned areas. Shrub frequency and cover, and herb frequency, were documented for different kinds of disturbances and environmental characteristics. Data concerning vegetation relations with north and south exposures, density of tree canopy and undercover characteristics, years since disturbance, elevation, latitude, slope position, and soil characteristics were presented. The interrelations of selected environmental factors were statistically tested. Significance was reported for shrub cover relations with type of disturbance, years since disturbance, and tree cover. Community structure was not well defined within the seral covers. Composition had a relation to exposure, past disturbance, and tree canopy cover. Characteristic groupings of species and limited species ecologies were discussed.

Lyon (1976) has described the succession, cover, and independent vegetal trends on the Sleeping Child wildfire burn in the Bitterroot National Forest, Montana, much of which area had been modified after fire by several management treatments. Lyon (1971) quantified similar postfire vegetation responses following a prescribed fire in Douglas-fir forest in central Idaho. Similar studies were made of an adjacent 20-year burn to extend findings into a longer term predictive model of herb, shrub, and tree cover responses following prescribed fire. Composition estimates were made from his model and are attached in the appendix as Table 3A.

Giles and Snyder (1970) formulated a model to simulate postfire succession, forage production, and grazing capacity. Forage production is extrapolated from animal-unit defecation rates, which is measurable in the field, estimated daily forage needs, and their assumed relation to total forage production. Six basic successional surveys for three elevational zones, with and without Ceanothus due to its greater fire response than other genera, provide curves that predict forage production at various time periods following fire (and other disturbances) for shrub winter ranges in Region 1 National Forests (Cf. Region 1, U.S. Forest Service Wildlife Surveys Handbook, Table 5, 190-5). Giles and Snyder noted that the mathematical form of the 01-type succession curve following fire is:

$$y = 0.04X^3 - 3.41X^2 + 80.35X - 68.02$$

These curves are being transformed into functional equations which can be used to predict production. Grazing capacities are relatively simple conversions of production data by known animal-unit forage requirements with a constraint imposed on how much current years' herbage must be left to maintain forage production and stabilize site -- usually about 50 percent or more (Region 1 Range Management Handbook prescribed 25 percent use of key grasses for cattle; Giles and Snyder suggest 50 percent total use is allowable). Giles and Snyder have introduced one other quality factor into the grazing capacity determination equation: scalars are used to account for differences in protein, elevation, and distance to cover from feeding areas. Nutrient content of most shrubs and herbs can be obtained from regional treatments, e.g. Cook (1972).

Basile and Jensen (1971) provide production trend lines for lodgepole forests after clearcutting and slash burning. Separate production curves are given for sedge, grass, forbs, shrubs, and total between 2 and 17 years following disturbance. Total production rose from about 250 to a peak of about 800 pounds per acre between years 10 and 12. Sedge production was minor and unchanged at less than 100 pounds. Grass production rose from about 75 to a peak of 150 pounds per acre between years 10 and 12, while shrubs rose from about 50 to a peak near 250 pounds at the 15th year. Forbs rose from near 150 to about 350 pounds at about 10 years following disturbance.

Scalings of percent composition by weight for the 2nd through 5th year, 10th, 15th, and 17th, last, year are found in Table 3B in the appendix.

Due to variations in tolerance to fire and highly variable conditions of environment in various forested regions, no simple general pattern of postfire succession can be inferred (Ahlgren and Ahlgren, 1960). However, generally, studies in the Rocky Mountains have found that wide-spread forest fires are usually dominated by herbs for a short period, often for the first five to ten years, and shrubs dominate for a somewhat longer intermediate period until tree regeneration shades or supresses undercover. The earliness of dominance of the major life forms and particularly of individual species, as noted previously, is dependent upon tolerance of each species and its regenerative and competitive potential to dominate. Hence, a knowledge of the fire responses of individual species and communities is fundamental to understanding and predicting fire successions.

Several authors have noted that most of the members of postfire successions are species which were present before fire (Lyon and Stickney, 1976; Ludi cited by Ahlgren and Ahlgren, 1960). However, McMinn (1951) found that successions varied due to preburn vegetation, seed source, and habitat conditions. Investigators have noted that major trends in revegetation of burns in forests are closely associated with species which sprout after fire, have fire-resistant seed in soil, or which combine fire survival or wind disseminated seed or vegetative sprouting (Kujala, cited by Ahlgren and Ahlgren, 1960; Lyon and Stickney, 1966). McLean (1969) found that root systems and depth of rooting, or of perenneating buds, had a close relation with fire tolerance or susceptibility. He classified 36 species of herbs and shrubs in Douglas-fir, logdepole pine forests into three categories; ten were fire-damage susceptible due to fibrous roots or rhizomes which develop in duff above mineral soil; four were "resistant" and had rhizomes or fibrous roots deeper than 5 cm in mineral soil or taproots. Of the latter four, common snowberry and birchleaf spireae are low shrubs, while the forbs, lupine and miser milkvetch, more commonly known as timber milkvetch, are both livestock poisoning plants. Those which were intermediate in fire tolerance had fibrous roots or rhizomes at depths of 1.5 to 5.0 cm in mineral soil and include fireweed, pine reedgrass, grouse whartleberry, creeping hollygrape, pachistima, wild peavine, American vetch, yarrow, and several forbs.

Bracken fern (Pteridum aquilinum) and fireweed willowherb (Epilobuim angustilioum) are semi-cosmopolitan, boreal, cold-temperate species frequently mentioned as early seral dominants after fire which may

become dense and suppress forest regeneration. Both are rhizomatous and the latter is a heavy seed producer with silky seeds which are readly airborne. Ceanothus spp. especially redstem and snowbrush ceanothus (C. sanguineus and velutinus) are vigorous fire-induced sprouters which also have dormant seed which can lie in the soil for a century or more and germinate. A second fire after these species attain maturity can further stimulate the stand to thicken from basal sprouts. Lesser species sometimes dominate early successions unexpectedly as, for example, biennial dragonhead (Dracocephalum parriflora) which dominated first year covers in the Neal Canyon burn in Idaho. While grasses often are stimulated by the altered environment induced by fire (Cooper, 1960; Weaver, 1951; Stahelin, 1943) including the effects of nutrients in the ash (Curtis and Partsch 1950; Burton, 1944), marked differences in fire responses do occur. Blaisdell (1953) noted that Idaho fescue is injured by fire while associated bluebunch wheatgrass (Agropyron spicatum) is tolerant and increases afterward. Similarly, while most warm season rhizomatous grasses in central U.S. appear to be favored by spring burning, Kentucky bluegrass, a cool-season rhizomatous grass, is injured, often severely, probably due to its more advanced stage of development.

Weaver (1951) observed the effects of prescribed burning on the perennial grasses in ponderosa pine, Douglas-fir, and western larch forests in the Coville Indian Reservation in Washington. Surface fires were set from prepared firelines in the fall to run down slope and against the wind for purposes of thinning dense stands of reproduction and accumulated fuels after logging. He wrote that most perennial grasses, chiefly Calamagrostis rubescens, Agropyron inerne,

and A. spicatum, Festuca idahoensis, Festuca ovina, and Koeleria cristata, were apparently not damaged by fire. He observed that Calamagrostis and Agropyrons, in particular, seemed to be stimulated to greater seed stalk production and height growth. Where excessive slash and intense fires occurred, revegetation was slowed for about three years.

FIRE ADAPTATION AND REVEGETATION STRATEGIES

Lyon and Stickney (1976) detailed the variety of adaptations and strategies for surviving fire in the northern Rocky Mountains. These include crown sprouting for a majority, heat treatment for some seeds before germination, and wind dispersal of seeds for herbs, and shrubs. Conifers are non-sprouters; some have cone serotiny; light, winged seed; or fire-resistant bark, with many requiring mineral soil for seedling establishment. These adaptations are further classed as functional "on-site" (in burned area) or off-site adaptations. A majority are on-site; off-site species of significance also have some on-site adaptive facility.

On-site adaptations, i.e., surviving plant parts, seeds, or fruit, are of major import on large burns, and amounted to 60 percent of specie in the first year postfire successions studied. Seed and fruit were about 20 percent of surviving on-site species. Intense tree removing fires caused survival from plant parts at or below ground and include: 1) root crowns of tall and intermediate shrubs, broadleaf trees, and cudaceous herbs; 2) rhizomes of low shrubs, herbs; and, 3) deep underground stems (bulbs, corms) of a few herbs.

Root crown sprouting was the major fire-survival adaptation of shrubs in three fires studied by Lyon and Stickney, comprising 50 percent of shrub species. Survival by regrowth from rhizomes accounted for one-third of all species present first year after two fires. Herbs with underground stems were minor, only up to 6 percent after fire.

On-site seeds accounted for 10-30 percent of first year successional species; survival strategies varied from no fire resistance to specialized seeds with extreme longevity but requiring heat to germinate. About 10 percent of first year species were in this class. Off-site species comprised 30 percent of first year species composition, but up until the fifth year off-site species' contribution to cover was minimal. Exceptions were Epilobium angustifolium with high cover values due to abundant off-site seed fortifying rhizome and rootcrown sprouting on-site.

They presented a model to the strategies for fire survival and postfire revegetation. Their appendix details the common species' strategies for fire survival, of value in predicting postfire successional cover and composition.

Vaccinium species comprise a dominant understory complex in many habitat tyes in the Bitterroot Mountains. Miller (1977) found that the number of stems 1 and 2 years after burning Vaccinium globulare, blue huckleberry, was most closely related to the number of prefire stems. Spring fires increased stem numbers; no seasonal variation in physiologic sprouting ability was evident; the number of stems after fire depended upon the fire treatment of stems and rhizomes. Spring fires consumed chiefly fine fuels and soil moisture protected the rhizomes so that only stems were pruned. In fall, dry large fuels often

burned too and rhizomes were burned due to low soil moisture and greater amount of heat released. Miller parameterized moisture levels that promoted and inhibited Vaccinium sprouting. She observed that "similar moisture levels may control responses of other rhizomatous species such as Spiraea betulifolia and Symphoricarpos albus, but was concerned that crown-sprouting species such as Menziesia and Amelanchier might be quite different. Her moisture parameters for promoting or inhibiting sprouting of Vaccinium globulare in the Pseudotsuga menziesii/Vaccinium globulare habitat type on the Lubrecht Experimental Forest were:

	Promotion	Inhibition
0-0.635cm fuel moisture content	under 12%	under 19%
upper duff moisture content	over 25%	under 70%
lower duff moisture content	over 100%	under 70%
soil moisture content	over 30%	under 19%
large fuel moisture	high	
	(will not burn, or difficult to ignite)	(will burn, easy to ignite)

Leege (1969), in dealing with the big game habitat problem in the Northern Rocky Mountains noted that three of the four key winter-forage shrubs, willow, serviceberry, and mountain maple have grown too tall for use, while redstem Ceanothus is vanishing, and large herds are declining. Earlier work, he reported, on the St. Joe National Forest had demonstrated that burning was feasible for stimulating browse. Lochsa River burning studies on previously burned mixed conifer and browse types caused little change in herbaceous cover but increased bare ground and reduced litter which only partially recovered in three years. Erosion was reported as minimal but incipient gullying occurred on certain firelines. Leege noted that all shrubs sprouted but variably.

Willow, mountain maple, serviceberry, and ocean spray sprouted most vigorously; redstem Ceanothus, bitter cherry, cascara, and syringa less vigorously. Fall burning reduced sprouting compared to spring but longer sprouts partially compensated. After three growing seasons sprouts were approaching the 7 foot ceiling of availability. Burned browse sprouts were preferred two years after fire and were browsed to a larger twig diameter than unburned control plants. Some forage nutrient changes were noted. Woody seedling counts showed that fire stimulated redstem Ceanothus to germinate in quantities sufficient to restock the area but with four times as many germinules from hotter fall fires.

Cooper (1960) monographed changes in vegetation pattern in ponderosa pine forests of the Southwest and noted that grazing and fire control were causing a build-up of thickets of younger aged pine which constituted a fire hazard. Denser forest overstories were reducing herbaceous ground cover. He noted an inverse tree crown cover relationship with forage production from predominantly Muhlenbergia virescens and other grasses in an equation:

$$V = 1600 - 21C$$

where V is herbaceous cover in pounds per acre, and C is the percentage of crown cover. Pre-settlement forests were kept more open by frequent surface fires, which thinned younger saplings, reduced surplus fuels and opened the site for herbaceous vegetation. Cooper (1961) noted that soil exposure and soils movement were significantly increased by burning, but the less than one inch of topsoil removed, was moved a

short distance down slope where it was stabilized in nine months. Humus accumulation was reduced from 61,000 pounds per acre to 52,000 pounds. Some changes in the physical characteristics of burned humus were noted, but he found that there was no difference in its water holding capacity.

Fuller et al. (1955) tested the changes induced by fires upon soil chemical, physical, and microbial characteristics in ponderosa pine forests having soils derived from volcanic ash parent material in northern Arizona. Fire destroyed the duff, souce of most nutrients; soluble salts derived from the duff's ashing caused an increase in pH, soluble available phosphorus, exchangeable bases, and total soluble salts and a decrease in organic matter and C/N ratio to a depth of 8 to 12 inches. Burning caused greater surface soil dispersion and greater compaction from raindrop action resulting in reduced permeability. Microbiological activity of soil decreased slighly in close relationship with fire intensity. Bacteria/fungi ratios increased in direct relation to fire intensity. Prescribed burning changed the original soil characteristics less than uncontrolled burning.

FORAGE PRODUCTION AND FIRE-INDUCED SUCCESSIONAL VEGETATION

Several forage production studies are reported in the literature. The six successional production curves in Region 1, U.S. Forest Service Handbook, Table 5, 190-5, explained by Giles and Snyder (1970) were noted earlier. Also, Basile and Jensen (1971) have developed curves for total, shrub, forb, grass, and sedge production after clearcutting and burning of eastside Montana lodgepole pine forests. Their multiple

regression analyses identified that the factors which most affected forage production were years since clearcutting, moisture represented by the combined field capacity of the A and B soil horizons, and sand content of A horizon. Another alternative predictor, nearly as effective but less easily obtained, was the available potassium and sand content of the B horizon. Two equations incorporating the above predictors were suggested for interim use.

Mueggler (1972) studied phenology and herbage yields of natural grassland sites, similar to forest margins or parks, on contrasting northeast and southwest exposures at two elevations in southwestern Montana. Festuca idahoensis dominated the vegetation with a variety of Palouse-flora forbs; soils were derived from limestone; precipitation ranged from 20-30 inches, about half coming in May and June. A highly significant R^2 coefficient of determination of 0.86 was associated with five factors: X_3, May precipitation; X_7, maximum air temperature, degrees F., in July; X_8, maximum air temperature (degree-hours) in June; X_{11}, minimum air temperature (degree-hours) in June; and X_{14}, maximum temperature (degree-hours) of shaded soil surface in June. The equation used to estimate total herbage production (Y_1) has a standard error of estimate of 83 lbs/acre (mean production, 1030 lbs./acre):

$$Y_1 = 1,194 + 169X_3 - 19.2X_7 + 2.40X_{11} + 3.50X_{14}$$

Similar predictive equations are given for forbs and grasses. The grass equation factors are the most readily obtainable from standard or fire weather stations and requires: May precipitation, maximum air temperature in July, and wind velocities in June and July. Forbs

constituted 57 percent and grasses 43 percent of production. (For rough measures, the grass predictor might be tried for lodgepole types and doubled for total yields on a trial basis.)

(It should be noted that extrapolating regression predictors from one locality to another is subject to considerable potential error. Basile and Jensen's study was on the Gravelly Range at 7100 and 8200 feet elevation and May was the key precipitation month for predicting effective growth. Lyon (1976) concluded on the Sleeping Child Burn in the Bitterroot National Forest that April precipitation was growth-effective and that May could not alter April's influence in promoting growth of dominant shrubs.)

Pase (1958) performed one of the few studies involving browse a a part of total forage production relations to tree canopy cover. He found a logarithmic relationship between total forage production and second-growth immature ponderosa pine crown-canopy, basal area, and pine litter in the Black Hills. Uncercover species were mostly different than northern Rocky Montain species; among those somewhat similar, Kentucky bluegrass declined with increasing overstory, bearberry was most abundant in the 0-40 percent cover class, while common juniper persisted in denser canopies.

Pine litter varied from 0 to 19 tons per acre. Thinning pine beyond accepted silvicultural stands was suggested on deer winter ranges to increase browse, but browse made the least forage response to thinning.

A variety of equations have been suggested for fitting regression lines using data for tree cover, the independent variable, and herbage

production as the dependent variable. Jameson (1967) used three sets of data for Arizona pinyon-juniper woodlands and ponderosa pine-bulch-grass ranges. He found a good fit and suggested as a general model for overstory-understory relationship, use of a 5-parameter transition sigmoid growth curve:

$$Y + H + A\,(1-e^{-B(X-G)})^{M+1};$$

X is the independent variable, Y is the estimated value of the dependent variable, and H and A are the upper and lower asymptotes, respectively. B provides the necessary curvature, m adjusts the inflection point, and G ajusts the value of X so that X-G=0 when Y equals H. Further instructions in the use of the equation are given.

FORAGE LITTER

Dyksterhuis and Schmutz (1947) classed plant materials into green herbage or forage, cured herbage or forage, fresh mulch, and humic mulch. Quantities of green herbage, fresh mulch, and humic mulch were obtained throughout one year on unused and different conditions of past use of Ft. Worth prairies. Herbage peaked in quantity in June - July period and "lows" occurred during winter months and bottomed out in June, while humic mulch peaked in the fall. Authors suggested that temperatures, moisture, periods of greater growth and frost, and the interrelations of these factors, contribute to the peaks and troughs of herbage and mulch fractions.

Hopkins (1954) observed that "from three to four years were usually required for the decomposition of vegetative material on the soil.

"...observations were verified by placing known amounts of mulch, ranging in air dry weight from 200 to 1800 grams, on each of 20 square-meter quadrats denuded of natural mulch, ... in April, 1950."

By June of the second year, 40 to 6 percent of the initial weight had been lost, leaves had disintegrated leaving fibrous material. By the third year, basal portions were intermixed with mineral soil, leaves were mostly decomposed, and stems were very fragile. He noted that the study period was favorable for decomposition with above average precipitation at Hays, Kansas.

Brown and Marsden (1976) have developed equations for estimating fuel loading of grasses, narrow-leaved forbs, broadleaved forbs, and small woody plants common in western Montana. Plant height and ground cover percentage were independent variables. Reasonable estimates were made from the equations with data sets from similar type vegetation. Brown (1975) also developed linear regression equations for predicting aboveground biomass and leaf weight from basal stem diameters for three classes of shrubs common in the northern Rocky Mountains. Rather high coefficients of variation were found and some positive skewness was noted. Although the author makes suggestions for minimizing field work in sampling, he also notes that shrub biomass varies considerably by habitat type and stand history and requires further study.

Martel and Paul (1970) noted that turnover of organic carbon can be described by two mathematical equations or by graphs on semi-logrithmic paper. The first equation shows the decomposition of the original plant components $(-dP/dt)$ as a sum of exponential functions:

$$-dP/dt = \sum_{(i=1)}^{m} K_i P_i,$$

where (m) stands for the number of different uniformly decomposable constituents in plants, (K) for the rate of decomposition, and (P, for the original amount of each component in plant.

Gilbert (1975) incorporated death and decay processes into his grassland simulation model, processes that flow to non-green plant biomass and litter compartments. Non-green material accumulates when respiration exceeds photosyntehsis or when extreme abiotic factors kill plants. This material is modified by temperature and soil water functions driving decomposition resulting in flow of material to the litter compartment. Grazing further modified material flowing into the above two compartments.

Hunter (1975) in a multiresource model of the Little South Poudre River unit of the Roosevelt National Forest shows that if average monthly temperature is not between 2 and 34 degrees F. growth does not occur and forage death is calculated as in the Gilbert model. The effect of temperature on forage disappearance is a linear function with disappearance rising with rising temperature. The effect of soil water on disapperanace is also an increasing linear function of the amount of soil water. These two factors are multiplied to determine the proportion of forage that dies in each forage class. Forage death is increased with wildfires and the amount of forage lost increases with the size of the fire.

Hunt (1978) presented a simulation model for decomposition in grasslands, which is the 1973 version of ELM developed as a part of the International Biological Program's grassland biome project. He treated substrate material as being heterogenous and assumed that it was composed of two fractions, the rapidly and slowly decomposing fractions. He recognized that decomposition rate is greatly affected by water and temperature. From experiments he extrapolated and formulated a curve of decomposition rising to a peak at about -0.5/bars of water tension and diminishing to nearly 0 at -15 bars. Similarly models were designed from experiments that show decomposition rates of soil at 0 and 38 degrees Centigrade. Inorganic nitrogen in the soil is simulated in the nitrogen submode. Then, the rate of decomposition in soil is a function of the effect of moisture, temperature, inorganic nitrogen, and a rate constant, value of which varies according to soil and nature of decomposing material. Validation tests showed a reasonably close fit to sample data particularly for the last half of 5-month test with litter bags buried at 5cm soil depths on the Pawnee biome site.

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APPENDIX

FORAGE SUBSYSTEM

The following tables document plant species in successional sequences after fires. They are reproduced in this appendix, rather than in the text, because of their length. The information in these tables is useful for representing both local and regional patterns of postfire succession by either species or plant groups.

Table 1. Habitat types and phases in sample of 200 plots in Bitterroot National Forest, Montana (adapted from Pfister et al., 1977).

HABITAT TYPES/PHASES	NO. PLOTS
SCREE (Rocks or landslides)	3
Pinus ponderosa/Agropyron spicatum	2
Pinus ponderosa/Festuca idahoensis, F. idahoensis	6
/Festuca idahoensis, F. scabrella	2
Pinus ponderosa/Purshia tridentata, Agropyron spicatum	2
/Purshia tridentata, Festuca idahoensis	1
Pinus ponderosa/Symphoricarpos albus, S. albus	3
Psuedotsuga menziesii/Agropyron spicatum	1
Psuedotsuga menziesii/Vaccinium caespitosa	2
Pseudotsuga menziesii/Physocarpus malvaceus, P. malvaceus	7
/Physocarpus malvaceus, Calamagrostis rubescens	4
/Vaccinium globulare, A. uva-ursi	3
/Vaccinium globulare, Xerophyllum tenax	7
/Linnaea borealis, Calamagrostis rubescens	1
/Linnaea borealis, Vaccinium globulare	2
Pseudotsuga menziesii/Symphoricarpos albus, Ag. spicatum	4
/Symphoricarpos albus, Calamagrostis rubescens	10
/Symphoricarpos albus, S. albus	2
Pseudotsuga menziesii/Calamgrostis rubescens, A. spicatum	3
/Calamagrostis rubescens, A. uva-ursi	5
/Calamagrostis rubescens, C. rubescens	5
Picea/Galium triflorum	1
Abies grandis/Xerophyllum tenax	1
Abies grandis/Clintonia uniflora, C. uniflora	2
/Clintonia uniflora, Aralia nudicaulis	1
Abies grandis/Linnaea borealis, L. borealis	2
Abies lasiocarpa/Clintonia uniflora, C. uniflora	4
/Clintonia uniflora, Aralia nudicaulis	2
/Clintonia uniflora, Vaccinium caespitosa	1
/Clintonia uniflora, Menziesia ferrugina	2
Abies lasiocarpa/Galium triflorum	4
Abies lasiocarpa/Calamagrostis canadensis, C. canadensis	6
/Calamagrostis canadensis, Galium triflorum	1
Abies lasiocarpa/Linnaea borealis, L. borealis	5
/Linnaea borealis, Xerophyllum tenax	3
/Linnaea borealis, Vaccinium scoparium	1
Abies lasiocarpa/Menziesia ferrugina	14
Abies lasiocarpa/Xerophyllum tenax, V. globulare	11
/Xerophyllum tenax, Vaccinium scoparium	4
Abies lasiocarpa/Vaccinium globulare	1
/Vaccinium scoparium, V. scoparium	3
Abies lasiocarpa/Alnus sinuata	1
Abies lasiocarpa-Pinus albicaulis/Vaccinium scoparium	3
Abies lasiocarpa/Luzula hitchcockii, V. scoparium	11
/Luzula hitchcockii, Menziesia ferrugina	3
Larix lyallii-Abies lasiocarpa h.t.s.	25
Pinus contorta/Linnaea borealis c.t. (community type)	2
Pinus contorta/Vaccinium scoparium c.t.	3
Unclassified stands (ecotonal depauperate, or unusual)	6

Table 2. Species lists for stages of postfire succession in forests of the Bitterroot Mountains in Idaho (Larsen, 1929).

First Stage

Species	Common Name	Preferred Slope
Antennaria 'densiflora'	'pearly everlasting	South
A. racemosa	'everlasting	South
Epilobium 'palmeri'	willowweed	North
'Chamaenerion' angustifolium	fireweed	North
Geranium carolinianum	Carolina geranium	North
Salix scouleriana	Scouler willow	North
Spiraea lucida	shinyleaf spiraea	South
Solidago spp.	goldenrod	South
Monarda menthaefolia	mintleaf horsemint	South
Sidalcea neomexicana	New Mexico wildhollyhock	South
Xerophyllum tenax	beargrass	South

Second Stage

Species	Common Name	Mode of Reproduction	Site
Alnus tenuifolia	alder		Moist-Wet
Acer glabrum	mt. maple	sprouts or wind-borne	Moist
Betula 'fontinalis'	water birch	sprouts or wind-borne	Wet
Ceanothus velutinus	snowbrush ceanothus	sprouts or wind-borne	Dry
Cornus canadensis	Canada dogwood		Moist
C. stolonifera	redosier dogwood		Moist
Holodiscus dumosa	oceanspray	sprouts or wind-borne	Dry
Fragaria spp.	strawberry		
Lonicera utahensis	Utah honeysuckle		Dry
L. involucrata	bearberry honeysuckle		Dry
Prunus demissa	chokecherry		Dry
Ribes reniforme	gooseberry		
R. viscossissimum	sticky currant		
Rubus parviflorus	thimbleberry		Wet

Table 2 (continued).

R. strigosus	raspberry	Wet
Sambucus 'glaucus'	blue elderberry	Wet
S. 'melanocarpa'	black elderberry	Wet
Symphoricarpos 'racemosa'	common snowberry	
Sorbus 'angustifolia'	mountain ash	
Vaccinium membranaceum	big whortleberry	Dry
V. occidentale	western bog blueberry	Dry

Third Stage

Adenocaulon bicolor	American trail plant
Actaea rubra	red baneberry
Adiantum pedatum	maidenhair (fern)
*Boykinea heucheriforme	boykinea
Aralia nudicaulis	wild sarsaparilla
Circaea pacifica	Pacific circaea
Claytonia 'chrysantha'	springberry
C. occidentale	western springbeauty
Clintonia uniflora	queencup/cornlily
'Felix mas'	brittle/woodfern
Galium triflorum	threeflower bedstraw
Galium boreale	northern bedstraw
Limnia 'spathulata'	spathe springbeauty
Mertensia 'spathulata'	bluebell
Mentha canadensis	Canada mint
Mertensia ciliata	mountain bluebell
Osmorrhiza spp.	sweet-cicely
*Seraphis gigantea	hellebore
Streptopus amplexicaulis	twistedstalk
Trillium 'pedatum'	trillium
Valeriana 'spetentionalis'	valerian
*Montia fontana	montia
'Vagnera lilieacea'	false solomon's seal
Valeriana sitchensis	Sitka valerian
Veronica scutellata	marsh speedwell

Table 2 (continued).

Climax subordinates

Species	Common Names	Shade Tolerance
Arctostaphylos uva-ursi	bearberry	tolerant
Asarum caudatum	wildginger	intermediate
Berberis sp.	Oregon-grape	intermediate
Chimaphilla umbellata	pipsissewa	
Coptis occidentalis	western goldthread	tolerant
*'Fatsia' horrida	devil's club	
Heuchera ovalifolia	alumroot	
Linnaea borealis	twinflower	intermediate
Lycopodium selago	clubmoss	
Pachystima myrsinites	myrtle pachistima	intermediate
Pyrola 'uliginosa'	pyrola	tolerant
Claytonia 'chrysantha'	springbeauty	intermediate
Tiarella unifoliata	foamflower	
Viola glabella	violet	

* are species which grow along streams or in wet ground
' are scientific names out of date, consult synonymy lists.

Table 3A. Estimates of species composition of cover for the Neal Canyon Idaho prescribed burn (Lyon, 1971) in Douglas fir.

	Estimates from actual cover data					Estimates from Lyon's model projections						
Years	1	2	3	5	7	10	15	20	25	30	35	40
Herbs	100	100	86	79	69	50	39	29	28	22	22	18
Shrubs	-	-	14	18	27	33	45	47	43	39	36	33
Trees	-	-	-	3	4	17	13	24	29	39	42	49

Table 3B. Estimated forage-class composition of forage production, in percent, for Eastside Montana lodgepole pine clearcuts followed by burning (Basile, Jensen, 1971).

Forage Classes	Years since area was clearcut and burned							
	2	3	4	5	7	10	15	17
Sedge	22	19	17	15	12	9	10	11
Grass	25	26	26	25	22	20	25	27
Forbs	39	39	40	40	43	44	29	23
(Herbs)	(86)	(84)	(83)	(80)	(77)	(73)	(64)	(61)
Shrubs	14	16	17	20	23	27	36	39

Table 3C. Estimated forage-class composition of postfire successional vegetation, abstracted from 3 fires studied by Lyon, 1976* in Montana and Idaho forests based on cover.

Forage Class	Postfire years					
	1	2	3	4	5	6
Herbs	87	89	80	75	67	64
Shrubs	13	11	20	25	33	36

*Note his Table 1 and that each fire is unique in early stages, up until about the fifth year.

WILDLIFE SUBSYSTEM

Lee Rayburn

INTRODUCTION

The purpose of this general review is to organize pertinent literature encountered to date as it relates to the wildlife submodel objectives. The principal objective of the subsystem is to simulate, through time, the effects of natural and prescribed fires on specified components of wildlife habitat on sites in the Bitterroot and Arapaho-Roosevelt National Forests. Direct output is aimed at expressing this habitat response through four categories of information useful to the planning/management level decision making process: 1) elk and deer population dynamics - including population size, density, and structure (specifying the potential harvest); 2) sport fish population and harvest indices; 3) terrestrial species diversity index; and, 4) unique effects such as threatened or endangered species involved.

In addition to these external outputs, the submodel also has as objectives the generation of useful information for input to other submodels and accepting return information from other submodels. The internal outputs will include: 1) wildlife effects on forest regeneration and growth; 2) seasonal wildlife forage consumption rates; and, 3) potential deer, elk, and fish harvests and index of species diversity. Information input from other submodels will be: 1) vegetative composition; 2) vegetative structure information; 3) forage availability by type or species;

4) abiotic factors (water, quality); and, 5) consumptive recreational use of deer, elk, and fish. User-generated input will consist of initial conditions and output specifications.

Models as abstractions of reality have a multitude of forms, depending on the exact use. Fullerton (1975) states that, "It is the mathematical dynamic model which seeks to represent the processes as they operate within the system", and it is this flow-oriented type of system that is being constructed for fire effects simulation. Differential equations (or difference equations) will be used to express flows of material and information with the SIMCOMP 4.0 simulation language (Gustafson and Innis, 1973). SIMCOMP 4.0 was designed to facilitate compartmental flow and discrete event (such as fire) simulations, and to provide various forms of output at specificable times.

Fullerton (1975) addressed the problem of model evaluation and concluded that a dual framework was necessary, including: 1) evaluation in terms of how well the model outputs serve their purpose (addressing the selected objectives); and, 2) piece-by-piece evaluation of the model structure. Previous simulations of wildlife populations and habitats (Cooperrider, 1973; Walters and Bunnell, 1971) are helpful in establishing a perspective for simulation when subjected to this evaluation procedure.

FIRE AND WILDLIFE (General)

With the exception of elk and deer populations, output from the simulation of fire effects on fish and wildlife is to be expressed in terms of indices (sport fish population and potential harvest index, terrestrial

species diversity index, and threatened or endangered species population index). Limitations on time and available information necessitate the reflection of these responses at the index level.

Sport Fish Indices

Kelsall et al., (1977) point out that adverse fire effects on fish populations are possible from increased flow, siltation, sedimentation, erosion, change of pH and change of water temperature. They conclude, however, that in the Canadian north, there is little evidence of prolonged or lasting effects on aquatic habitat. Thompson et al. (1977), report similar findings where there was no evidence of adverse effects on fish after a large fire on the Seney Wildlife Refuge in Michigan. The 84,000-acre Swanson River fire in Alaska produced a massive die-off of salmon and trout eight days after the fire, but this may have been attributable to the 281,000 gallons of fire retardent dumped in or near the river and its tributaries during suppression (Hakala et al., 1971). Four days after the die-off, the toxin had dispersed and healthy salmon were observed.

Terrestrial Species Indices

Response of terrestrial species will be calculated through changes in species diversity and relative abundance indices for various classifications by habitat type (ELU) and/or fauna type (avifauna, small mammals, etc.). Pertinent literature for calculation of these indices includes: 1) general fire effects on diversity; 2) fire effects on populations of individual

species; and, 3) formulation of mathematical relationships for actual index calculation.

In the area of general effects, Bendell (1974) has found relatively small changes in diversity of species before and after fires and believes this to be a function of evolution in a fire environment as well as a result of the tendency for wildfires to burn unevenly, leaving interspersed unburned areas. Additionally, he states that frequency of burns causes little or no decline in the number of breeding species in an area. Species diversity was greater on a burn five years after the fire than in adjacent lodgepole stands in the mountains of north-central Colorado (Roppe, 1974). A decline in breeding bird density and diversity was observed on the Waterfalls Canyon burn in Grand Teton National Park one year post-fire (Barmore et al., 1976). Kelsall (1977) evaluated small mammal responses and concludes that diversity and abundance suffer short declines at worst and usually there is no change.

Immediate, direct mortality from fire was once believed to be a major factor but is now recognized to be generally insignificant (Cringan, 1958; Hakala, 1971; and Bendell, 1974). A possibly significant direct effect is reproductive loss of immobile young (Cringan, 1958; and Bendell, 1974). Short- to long-term effects on the negative side include shortage of food and cover until vegetation recovers to the required state (long-term for climax species, short term for early successional species). On the positive side, fires often create a diverse vegetative mosaic of use to a greater number of species and may stimulate vegetative growth for herbivores (Bendell, 1974).

Responses of individual species to fire is the second category of information important in calculation of diversity/abundance indices. Koehler and Hornocker (1977) investigated fire effects on pine marten (Martes americana) and found that this climax related species did not necessarily suffer a decline after fire on an area as previously stated (Kelsall, 1977; Viereck, 1973), but that the exact response depended on fire characteristics and prey reactions. The grouse species have been the subject of numerous fire investigations and each species varies in the degree to which it is affected (Bendell, 1974; Kelsall et al., 1977; Thompson et al., 1977; Viereck, 1973; Hakala et al., 1971; Rowe and Scotter, 1973; Heinselman, 1973).

Fire effects studies have also frequently included cavity nesting species of birds. Thomas (1976) listed 38 species of birds that utilize cavities and expounded on the influence of environmental disturbance on the group. Kelsall et al. (1977) note the prevalence of suitable trees for cavity nesting flickers (Colaptes auratus) following fire, and the subsequent use of these cavities by buffleheads and goldeneyes (Bucephala spp.). An opposing view is that cavity nesters are favored by advanced succession and over-aged trees (Loope and Gruell, 1973). Some studies have reviewed large numbers of species and are also of value in attempting to measure fire effects with diversity and relative abundance indices. Kelsall, et al. (1977) provides an extensive review of fire effects species by species for the boreal region of Canada. Bendell (1974) is similar in approach and also lists a range of species and gross responses. Rowe and Scotter (1973), and Viereck (1973) have also done regional surveys of species, though on a less extensive basis; Heinselman (1973), Barmore et al. (1976),

and Thompson et al. (1977), have described responses of individual species in specific areas (Boundary Waters Canoe Area, Minnesota; Grand Teton National Park; and Seney Wildlife Refuge, Michigan, respectively).

The wildlife submodel will utilize this individual species response information in context with information on expected diversity response to calculate selected diversity and relative abundance indices. Krebs (1972) describes steps for calculation of the Shannon-Weiner index, which includes information on number of species and equitability of individuals among the species. Roppe (1974), in evaluating fire effects used the Shannon-Weiner index for species diversity and the Kruskal-Wallis test for relative abundance of birds and small mammals.

FIRE AND LARGE HERBIVORES

As presently conceived, the submodel outputs of deer (Odocoileus hemionus) and elk (Cervus elaphus) information are specific and at a level that will reflect effects of fire through vegetational changes in cover and forage. Establishment of functional relationships for ecosystem simulation of deer and elk population dynamics will be through interpretation of the literature which again may be divided into three categories: 1) general information on population responses to fire from fire ecology studies; 2) elk-deer habitat requirements and the degree to which they are met in different successional stages: and, 3) relationships of habitat structure and composition to processes of birth, growth, and mortality.

Population Responses to Fire (General)

Movement back into burned areas of deer and elk were observed one year post-fire indicating short term (if any) negative effects from the burn (Barmore et al., 1976), and Roppe (1974) observed significantly heavier elk and deer use of a winter range burn (five years post-fire) than of the surrounding area. Rowe and Scotter, (1973) and Leege (1969) reflect prevalent reports of positive response of mule deer populations to improved post-fire forage. With variance between plant species, the trend was to improved quantity and quality of browse immediately post-fire. Kelsall et al. (1977) related a study where browse protein levels increased immediately after a fire to a peak but had declined by 50 percent from that peak after six years. Further, they report a white spruce (Picea glauca) clear-cut where browse was still increasing in availability ten years after the cut.

Exceptions to the positive browse response are reported by Bendell (1974). A burn in Alaskan spruce (Picea spp.) regenerated to spruce with no browse peak, and a 31,000 acre fire on Vancouver Island in 1951 failed to produce any increase in deer as measured by hunter success. Loope and Gruell (1973) conclude that mule deer benefit from fire suppression, since sagebrugh (Artemesia spp.) in many parts of their range is a staple winter food item and it increases without fire.

The response of mule deer and elk to fire is therefore variable and may depend on fire characteristics among a complex of other factors. Frequently, however, the trend is for immediate post-fire population increase as forage increases, with a leveling off for an intermediate period, and finally a decline in later successional stages.

Habitat Descriptions

This category of information ranges from area-specific yegetation descriptions and herbivore use of each, to detailed estimates of habitat requirements. Descriptions and requirements are in terms of cover, forage, and water.

Physical, specific descriptions of areas of interest are of value. Mackie (1970) describes vegetation and use by deer and elk, including distribution, movements, and use of habitat types, slopes, and water. He further describes food habits by season and range relations to deer, elk, and cattle. Habeck's (1972) study in the Selway-Bitterroot Wilderness of Montana includes excellent physical and vegetational descriptions of successional types. Lyon (1966) evaluated aspects of habitat that are frequent problems. Included are the complexity of palatibility and preference variability from one plant species to another, seasonal variations in cover requirements, and winter severity as the determining factors in winter range overuse and slow response.

The abundant literature on elk and deer habitat requirements provides accurate descriptions of forage consumption rates, nutritional values, etc., but has much more limited information regarding quantitative cover needs. Currie et al. (1977) studied deer and cattle use of an area in Colorado in terms of forage consumption, preference, and competition by basal area classes. Elk distribution patterns and habitat use in northern Idaho have been related to snow depth, aspect, elevation, slope, winter severity, and vegetative type. In this study (Leege and Hickey, 1977), snow depth (maximum of two feet tolerated) and quantity of forage played major roles, and a function was given for relating snow depth

to aspect and elevation. Elk use of clear-cut openings (analagous to burns in some ways) has been reviewed in western Montana (Lyon, 1976). Independent variables associated with clear-cut use were vegetation height in the clear-cut, slash depth, slope-aspect-elevation, down timber in adjacent forests, size and shape, water, vehicle access, and nearest clear-cut. Estimates of ranges of acceptable values for some of these factors are given.

Black et al. (1977) in a comprehensive study in the Blue Mountains of Oregon, and Washington attempted to roughly quantify deer and elk needs for food and cover as guidelines for timber management. Optimum habitat was defined as 40 percent cover and 60 percent forage areas. Definitions are given for hiding and thermal cover as well as reproductive cover for both species. Suggested optimum percentages for types of cover are also listed. Forage areas are all openings and all forest less than 70 percent closure (60 percent for deer) or forest that will not hide 90 percent of an elk at 200 feet. Use of openings is related to size and shape for both species.

Relating Habitat to Population

The process of relating population dynamics to habitat parameters is sparsely documented in the literature. Black et al. (1977) do present rough quanitification of population responses of elk and deer to different proportions of cover and forage. Nutrition studies are useful in estimating animal condition as a function of nutrient intake (Gasaway and Coady, 1974; Morris and Kovner, 1970). Modeling studies relating

population dynamics to forage availability, quality, and consumption (Cooperrider, 1973) are of value in demonstrating methods of linking certain aspects of habitat to birth and death rates.

SUMMARY

This general look at the literature involved reveals abundant information for simulation in some areas and a serious shortage in others. In establishing functional relationships, the number of parameters involved will be limited in some cases by this shortage of information and broad assumptions will be necessary in other cases. The modeling process will hopefully enable optimum use of available information and aid in defining the kinds of information needed to evaluate the effects of disturbances such as fire on wildlife habitat.

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HYDROLOGIC SUBSYSTEM

Phil Guertin

INTRODUCTION

The purpose of this review is to gather pertinent literature regarding the effects of fire on the hydrologic subsystem, to be used in the development of a simulation model.

The outputs from this model will answer both external and internal questions asked of the hydrologic submodel. The external outputs will be centered towards the management/planning aspect of the National Forest system, and will consist of very broad indicators of fire-watershed impact.

The external outputs of the hydrologic submodel will be water yield (ac-ft/yr), sediment yield (tons/acre/yr), and water quality (ppm). Water quality will be dealing with only the four major nutrients: nitrogen, calcium, potassium, and phosphorus.

The internal outputs will be responses to demands generated from the other subsystems for hydrologic data. These outputs were stated in detail in the Study Plan.

To be able to predict the internal and external outputs through simulation, we must understand the processes that influence them and what impact fire has on them. The rest of this paper will be a discussion of the hydrologic processes that control the external outputs (erosion, infiltration, nutrient cycling), and those environmental factors

that influence hydrologic processes and the effect of fire on these processes.

GENERAL

Many environmental factors have been proposed as controlling influences on the erosion, infiltration, and nutrient cycling processes.

In early studies in California, maximum 24 hour precipitation, barren area, topography, areas burned, and the burned area's cover density were the chief factors regulating erosion and peak discharge (Anderson and Trobitz, 1949). In California's San Gabriel Mountains; topography, geology, soils, and climate were the major factors controlling erosion (Sinclair, 1950). It was further stated that fire and certain land use would accelerate erosion through an increase in surface runoff. Other papers from Calfornia reported similar relationships (Anderson, 1949; and Rowe, 1943).

These earlier studies only looked at fire as a component in equations developed to predict erosion rate and peak discharge over large areas. Starting in the 1950's, studies were initiated to determine why fire caused this increase in erosion and runoff.

Friedrich (1955) listed ten factors that influenced how fire affected the system: 1) size and intensity of fire; 2) soil characteristics; 3) slope steepness; 4) amount and character of precipitation; 5) type of vegetal cover before fire; 6) length of time soil will be exposed before revegetation; 7) type and amount of vegetation that comes back after the burn; 8) proportion of the watershed unit affected by the fire; 9) characteristics of associated unburned portions of the watershed; and, 10) condition and ability of the stream channel to carry increased flows in an orderly manner.

Later this list was narrowed down to just four factors that were significant when trying to predict the effects of fire (Settegren, 1969; and DeByle, 1976). They are:

1. Climatic conditions after the fire event,
2. Topography conditions,
3. Soil type and the degree to which it has been disturbed by fire,
4. The extent that vegetal cover has been affected by fire and the time it takes to recover.

All four of these factors influence the three hydrologic processes to some degree, either directly or indirectly, but fire affects only the latter two. These two factors, soil and cover, will be the principal components in any prediction equation.

We will now see how climate, topography, soils, and vegetal cover control our processes.

CLIMATIC FACTOR

The most important climatic factors, when interested in the hydrologic system, are rainfall intensity, raindrop size distribution, and total rainfall.

Wischmeier and Smith (1958) demonstrated the importance of rainfall energy (a function of raindrop size and rainfall intensity) in the prediction of soil loss on agricultural lands. This same relationship was reported by Ekern (1950), and Tew (1973) used it in the prediction of erosion in southern Utah.

Striffler and Mogren (1971) correlated erosion rate to total precipitation and the maximum 30-minute rainfall in Colorado; and Anderson

and Trobitz (1949) used the maximum 24-hour precipitation in southern California.

The infiltration rate is also influenced by total precipitation and rainfall intensity. The Rational method developed by the Soil Conservation Service uses rainfall intensity to predict runoff rates. Other researchers have correlated runoff to total precipitation (Anderson and Trobitz, 1949; and Rowe, 1943).

Nutrient flow is related to total annual precipitation. Simply stated, areas with low annual precipitation produce low amount of nutrient outflow. On the other hand, areas that have high annual precipitation will have great amounts of free water leaving the system. This increases the chance for nutrient loss (Cole, 1966; and Cole et al., 1967).

TOPOGRAPHY

An area's topography has long been considered an important factor in the prediction of sediment and water yield. Slope is very important when predicting sediment yield. Wischmeier and Smith (1965) showed the importance of slope grade and slope length on eastern agricultural lands. An increase in slope gradient and length usually means an increase in erosion. This same relationship has been observed under wildland conditions. Models developed to predict erosion rate under wildland conditions have used slope as a factor (Duley and Hays, 1932; Dunford and Weitzman, 1955; Flaxman, 1972; and Tew, 1973).

Runoff is also a function of a number of topographic factors. First slopes up to 2 to 3 percent have a great affect on the production of runoff (Duley and Hays, 1932). This is because as the slope gradient increases surface water will have less time to absorb into the soil.

But as slope gradient gets steeper its effect is mitigated.

Other topographic factors have also been related to runoff of yield. The Rational method for determining peak flow rate and the SCS unit hydrograph method both use drainage and drainage length into their equations. Drainage type (dendritic, rectangular, trellis, etc.) has also been correlated to peak discharge.

SOIL

The impact of fire on the physical and chemical properties of soil is directly proportional to the amount of organic matter consumed by fire. The soil's moisture holding capacity, erodibility, porosity, permeability, and nutrient content are all related to the amount of organic matter that is destroyed.

Austin and Baisinger (1955) observed on forest soils in Oregon and Washington that immediately after a burn the water holding ability of the soil was reduced 33.7 percent and there was a 75 percent loss of organic matter in the top one-half inch of soil. Two years after the fire, the moisture equivalent still had not improved and the organic matter was still below 50 percent of normal.

Blaisdell (1953) found this same relationship in the Snake River country in Idaho. Here it was found that organic matter, total nitrogen, and the moisture equivalent measured one year after the burn were significantly reduced in the top one-half inch of soil.

Fuller (1955) found that the principal influences of severe burning on the physical properties of the soil were to increase the degree of dispersion and to decrease the permeability of the soil to water. Fuller also observed that burning decreased permeability and destroyed the

structure of the soil surface up to about three inches. Beaton (1959) has observed a destruction of soil structure at the surface decreasing total porosity. Auten (1934) reported the same in southern Illinois. Meeuwig (1971) showed that soil organic matter was very important in determining the erodibility of the soil.

Figure 1 shows the relationship between soil texture, organic matter, and relative erodibility. Finer soils decrease in erodibility as organic matter increases. Coarser soils will increase in erodibility as organic matter is increased. This is because, in fine soils, the organic matter acts as a cementing agent causing soil aggregates. But in coarse soils, this seems to have the opposite effect.

Other people have observed this relationship. Striffler and Mogren (1971) reported lower soil organic matter after a fire but also reported minimum erosion impact. This minor soil loss contributed to very sandy soils.

Pillsbury (1953) reported that heating to high temperatures tended to destroy the collodial properties of the soil.

Another theory why coarser soils tend to be more erodible is the influence coarse soils have on soil wetability. DeBano and Rice (1970, 1973) reported that some soils are hydropholic and will repel water, thus increasing overland flow and erosion. Sandy soils tend to be more susceptible to this phenomenon.

Soils are also a very important factor in controlling the flow of nutrients. Deep soils with a high clay content are able to retain the nutrients released by burning (DeByle, 1976). These soils have a high buffering capacity. Other soils have little buffering capacity and lose nutrients readily to the water system. An example of soils with a low

buffering capacity would be those at Hubbard Brook (Likens et al., 1970), where shallow, acid soils overlaid imperious bedrock. Nutrients were readily flushed from this soil and any shallow, very sandy soil should react similarly.

VEGETAL COVER

Vegetal cover is the most affected of all the hydrologic factors by fire. It is also the major controlling influence over the erosion, infiltration, and nutrient cycling processes.

Vegetal cover controls the rate of erosion by protecting the soil surface against the impacts of rainfall and overland flow (Kittredge, 1948).

High infiltration capacity of forest soils is due in part to its very porous structure. This porous structure is developed and maintained under a protective canopy and litter cover which protects the surface from the beating action of rain and resists the washing action of surface flow. Marston (1952) (Figure 2) measured the effect of ground cover on storm runoff under aspen in northern Utah.

When protective cover is disturbed by fire, erosion rate and infiltration rate are both affected. This has been well documented in the literature.

The affect of cover on erosion was well documented in a study by Meeuwig (1971) in the intermountain west. He observed that greater surface cover yielded less erosion. Figure 3 shows the relationship between slope, cover, and erosion (pounds/mi/acre).

Infiltration is drastically reduced by puddling at the soil surface caused by raindrop impact (Friedrich, 1955).

Decreased infiltration can also be caused by a decrease in transpiration. Transpiration was observed to be much reduced and soils remained wetter throughout the growing season making more of the summer precipitation available to streamflow (Johnston et al. 1969; Johnston 1975).

Rothacher and Lopushinsky (1974) observed that the quantity of chemicals that reached the stream is roughly proportional to the quantity of fuel burned. Broadcast burning after logging of old-growth Douglas-fir increased loss of nutrient cations 1.6 to 3.0 times that from unburned areas.

Broadcast burning in the Rocky Mountains produced slight increases in nutrient quantities in soil solutions at depths of .6 to .12 meters, but this increase was relatively short-lived (Hart and DeByle, 1975).

Stark (1976) reported that temperatures less than 200°C produced no nutrient loss. But, with surface temperatures greater than 300°C nutrient losses were greatly accelerated. These losses were not enough to damage the site quality of the area.

Nutrient loss was also observed to occur through volatilization. Large amounts of nitrogen, sulfur, and phosphorous were lost through this process (DeBell and Ralston, 1970).

Other nutrients such as calcium, potassium, and magnesium are substantially increased by fire (Austin and Baisinger, 1955). It has been noted that soil pH increases following fire (Austin and Baisinger, 1955; and Striffler and Mogren, 1971).

After fire has swept over a stream system, water temperature is increased by increased solar radiation. The increase in temperature is directly proportional to the degree that the stream is exposed to increased sunlight (Meehan, 1970; and Brown and Krygier, 1967).

It should be noted that all the effects caused by fire to both the

soil and vegetation of a watershed will disappear with time. As the vegetal cover returns to normal, the other components of the system (soil organic matter, replacement of nutrients, and decreased soil erodibility) will quickly follow suit. Many authors state this process to take three to five years.

SUMMARY

Most of the impact on the hydrologic system caused by fire results from the destruction of the soil organic matter and the soil cover. The decrease in soil organic matter results in decreases in soil water holding capacity, soil porosity, soil permeability, and increased soil erodibility.

With the destruction of vegetal cover, the soil's infiltration capacity is usually reduced. The exposed soil surface is also subject to increased erosion.

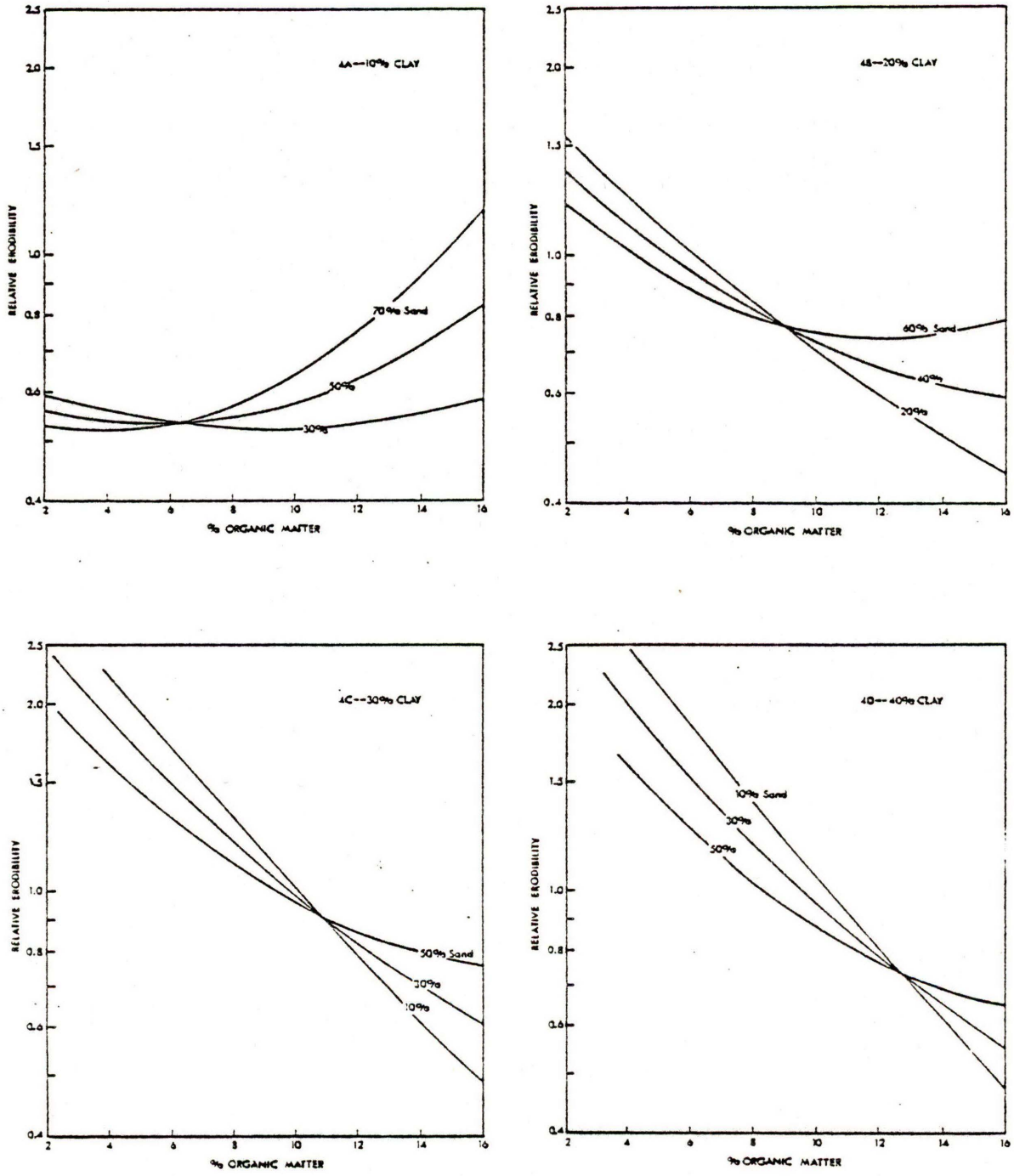

Figure 1. Relative erodibility as influenced by variations in sand, clay, and organic matter content of the surface inch of soil. Relative erodibility is the ratio of calculated erosion corrected for sand, clay, and organic matter to calculated erosion at average sand, clay, and organic matter. (Meeuwig, 1971).

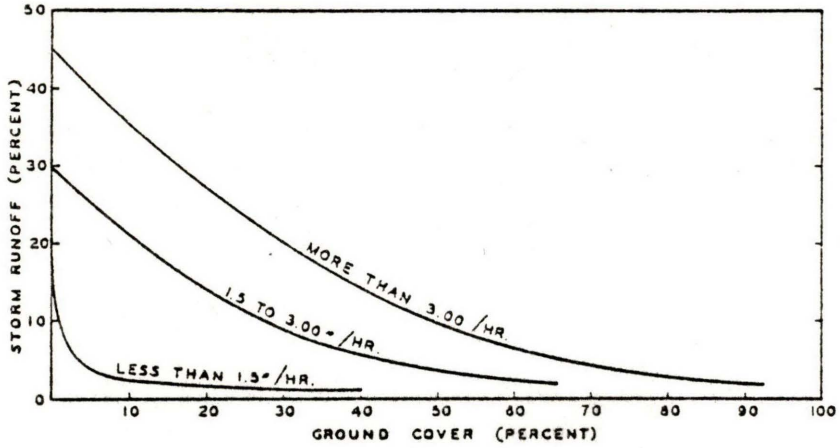

Figure 2. Relation of summer storm runoff to total ground cover under the impact of low, moderate, and high intentsiy rainfall rates (Marston, 1952).

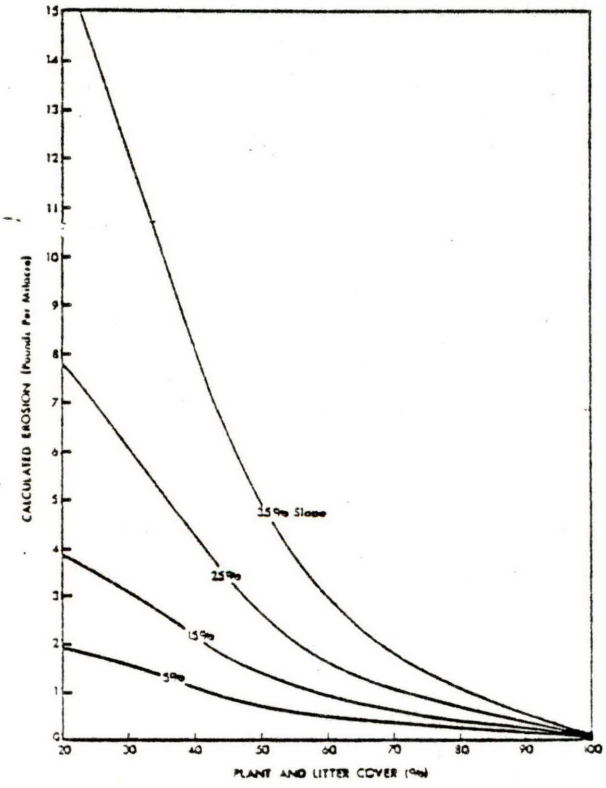

Figure 3. Erosion calculated as a function of slope gradient and percentage of the soil surface protected by plants and litter. Sand, clay, and organic matter are fixed at their respective averages of 30, 24, and 8 percent. (Meeuwig, 1971).

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RECREATION SUBSYSTEM

Michael Sieg and Perry Brown

INTRODUCTION

The principal goal of recreation resource management is to provide satisfactions and benefits to users consistent with certain administrative, budgetary, and resource constraints (Wagar, 1966). The problem is that user satisfaction is a multi-dimensional concept and is hard to identify. Recently many natural resource managers have become interested in managing natural resources to produce opportunities for specific kinds of quality experience. But they have no way of knowing which resource factors are perceived by users as essential for satisfying experiences (Brown et al., 1977).

The purpose of this report is to review the relevant literature that addresses the problem of defining certain characteristics that contribute to satisfying experiences for recreation. This will be done in order to judge how physical effects on the resource base, caused by fires of different types and intensities, will affect the supply of recreation opportunities available to consumers.

RECREATION - A USEFUL DEFINITION

There are basically two ways of defining recreation. The "conventional" approach is to define it as activity and the "behavioral" approach is to define recreation as an experience. A behavioral definition of recreation is more product-oriented and attempts to specify more clearly

what goods and services are demanded (Driver, 1975). A useful definition is that recreation is a particular type of human experience that finds its source in intrinsically rewarding voluntary engagements during non-obligated time (Driver and Tocher, 1970). Recreation demand can be defined in terms of preferences for specific satisfying experiences that are desired, expected, and sought from chosen activities (Driver, 1975).

Because demand for satisfying experiences is expressed by participating in an array of activities, it will be necessary to examine the literature that relates activity factors to sources of satisfaction.

ACTIVITY FACTORS RELATIVE TO USER SATISFACTION

Space nor time permits examination of activity factors related to user satisfaction for all possible outdoor recreation activities. The activities chosen were the general activities of camping, hunting, fishing, and dispersed recreation.

Camping

In a study done on the Superior National Forest of Minnesota, it was found that five factors of the natural environment in and around the campground resulted in higher rates of occupancy. They were: 1) a reputation for good fishing; 2) presence of coniferous trees; 3) deep offshore water; 4) bedrock outcrops; and, 5) cliffs. Two attributes of the cultural environment were significantly related to use: 1) camping areas with many waterfront campsites; and, 2) older, well-established campgrounds (Lime 1970).

In this study it was found that 77 percent of the variance in percent occupancy rate of the 29 camping areas studied was predictable from three campground attributes: 1) percentage of waterfront campsites; 2) reputation for fishing; and, 3) length of time the campground had been open. Of these three attributes, percent of waterfront campsites accounted for 65 percent of the variation in percent occupancy.

The statistical significance of water as an attraction of campgrounds is consistent with other studies (Beardsley, 1967; Shafer and Thompson, 1968; Lucas, 1970).

Some researchers have hypothesized that the type of trees may influence where people go for recreation, (Frissel and Duncan, 1965; Klucas and Duncan, 1967). Although coniferous tree cover was significantly associated with a higher intensity of use, there was little evidence that this or any other type of vegetation actually influenced visitor choice. Most campers were primarily concerned with being able to see the water, having a spacious and level site, and being well screened from neighbors, (Lime, 1970).

Fishing Experience

The literature related to factors that influence the satisfaction of fishing experience, points out that much more is involved than just catching fish.

The purpose of one study in New York was to provide some basic insights into the relative importance of factors that influence the overall enjoyment of a fishing trip. In this study, fishermen ranked factors in their immediate surroundings: water quality, natural beauty of the area, and privacy while fishing, as very important. Size of fish

caught and weather were ranked as important, (Moeller and Engelken, 1972). The size and number of fish caught and the access to fishing waters ranked fourth, sixth, and seventh, respectively, in an overall importance among the eight factors studied.

In a study of Ohio fishermen, results showed that more than half obtained as much enjoyment from a fishing trip if they caught no fish as they did if they caught fish (Addis and Ericksen, 1969). Other studies have shown that at least two-thirds of the nation's fishermen catch less than one-third of all fish caught, and that half of these fishermen catch no fish (Sport Fishing Institute). Another study done by Knoph et al. studies the motivations of selected groups of fishermen in Michigan. Studies by Tahelm (1973), Kennedy and Brown (1976) and Bryan (1977) have investigated some of the environmental setting attributes which contribute to satisfying fishing experiences. From their work, it is apparent that there are significant components of the physical, social, and managerial settings which affect the experience.

Hunting Experience

The basic products of wildlife management are human satisfactions and the overriding goal should be to produce desired and worthwhile human experiences (Hendee and Potter, 1971). Therefore, knowledge about the satisfaction, benefits, motives, and preferences of wildlife users, and how they vary under different conditions is important to help guide the resource manager.

There have been two general types of studies done on hunting experiences. One type has focused on the harvesting aspects of hunting and

the other on the non-harvesting aspects of the hunting experience.

In a Montana study, while success was not the only factor determining satisfaction, two-thirds of the 402 hunters responded that satisfaction was dependent on success (Stankey et al., 1973). The authors also concluded that dilution of the probability of success will lead to a decline in satisfaction level.

In a study of Arizona hunters Davis (1967), found that the benefits of bodily health, aesthetics, association with others, intellectual stimulation, character building, and religious factors were each important in characterizing hunting.

Nearly all investigators of the hunting experience have rated harvest as a positive attribute, although not as highly as one mght expect. For instance, Kennedy (1970) found it rated positively, but ranked fourth in his list of classifications. Moore (1973) found both "killing" and "display" of game neutrally rated factors with neither contributing much to the satisfaction of Massachusetts hunters. Other researchers who have studied the hunting experience include Brown et al. (1977) and Potter et al. (1973).

Dispersed Recreation Experiences

Recreational use of forest and other wildlands has increased steadily during the past decade. At least 75 percent of this increased use has been of a dispersed nature, (Brown et al., 1977).

Before managers can manage natural resources to produce opportunities for specific kinds of quality recreation experience, they must know which resource factors are percevied by users as essential for a satisfying experience.

In a study by Brown et al., (1977) of the Indian Peaks back-country, located south of Rocky Mountain National Park in Colorado's Front Range, physical resource attributes were identified from a list of 73 resource attributes as contributing to user satisfacton. In that study, nine dimensions of the resource base were identified which either added to or detracted from the user's recreation experience.

The item rated by the population to most strongly add to satisfaction was "clean fresh air", while "murky or discolored water" was rated as the most negative of the 73 items. In general, the most positively ranked items were those dealing with pollution-free environment and scenic beauty. The most negative were those dealing with man's impact and nuisances.

Dimension	Effect on User's Perceived Level of Satisfaction
Meadow-Forest	Adds Strongly
Water Related	Adds Strongly
Wildlife	Adds Moderately or Strongly
Dense Vegetation	Adds Moderately
Rugged Topography	Adds Moderately
Rare or Unique Natural Features	Adds Moderately
Fish Related	Adds Moderately
Nuisances	Neither Adds Nor Detracts
Intrusions	Slightly Detracts

Many other studies of dispersed recreation have been done. Some of them are Hendee et al. (1968), Lucas (1964), Peterson (1974), and Stankey (1973).

The Landscape Experience

The public concern with the aesthetic qualities of the natural

environment has given scenic beauty the status of an important natural resource. As the previously mentioned literature illustrates, the landscape is an integral component of most recreation experiences. The problem is that other resources such as timber and minerals can be objectively measured, but this has not, in general, been true for aesthetic values concerning landscapes (Daniel et al., 1973).

Systematic investigations of the problems of evaluating the scenic qualities of natural landscapes have been appearing with increasing frequency. Criak (1968, 1970, 1971) has formulated a system of landscape dimensions directed toward reliable evaluation of landscape quality. Leopold (1969) has constructed a set of scaled factors for measuring the aesthetic quality of wildlands. Shafer et al. (1968, 1969, 1970) have made substantial contribution to the quantification of scenic beauty and the evaluation of variability that influence user preferences. The volume of papers edited by Proshansky, Rivilin, and Aimbin (1970) contain several approaches to the measurement of aesthetic responses.

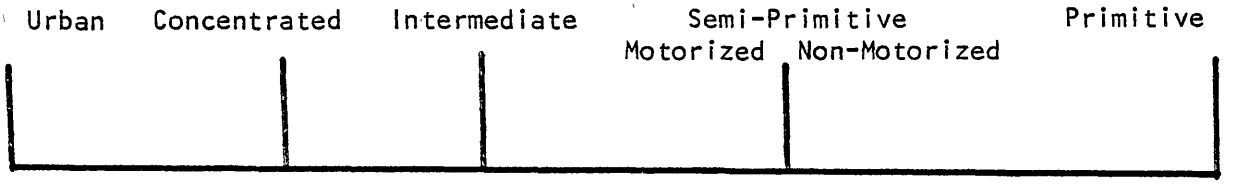
Daniel et al. (1973) applied a psychophysical measurement model that determines a person's aesthetic response to different types of landscapes. They found that certan landscapes were easily recognized as cases of human intervention and strongly disliked, relative to an untreated area. This is consistent with the view that "naturalness" is a desirable characteristic of forest landscapes (Lucas, 1964; Leopold, 1969, Twiss and Little, 1966).

ACTIVITIES, EXPERIENCES, AND THE FIRE EFFECTS MODEL

The objective of the fire effects model for recreation resources is to determine changes (amount and type) in recreation opportunities supplied due to forest fires of different kinds and intensities. To determine such changes requires that concepts of recreational activity and experiences and the environmental features supporting them be brought together. Brown et al. (1978) have suggested a way to do this and an overview of their ideas is below.

The supply of recreation opportunities can be viewed as the activity opportunities (e.g., hunting, camping) or as the experience opportunities (e.g., to experience nature, isolation, etc.) made available to consumers. Both occur in many settings which may be modified by fire. Since a purpose of recreation management is to supply satisfying recreation opportunities to consumers within constraints of the social, economic, political, and resource environment, a relevant conception of recreation opportunity is one that relates to the sources of satisfaction. When recreation opportunities are defined in terms of experience opportunities (Driver and Brown, 1978), they meet this criterion; when defined as activity opportunities, they do not meet it.

Experience opportunities can be arrayed along a spectrum of recreation opportunities (Wagar, 1966; Driver and Brown, 1978) as shown below.



For each location along the spectrum the opportunities can be described in terms of the set of phsychological outcomes they provide and the setting in which they occur. In fact, it is the combination of phychological outcomes and the setting which are used to define the experience opportunity. The experience opportunities with their general physcholological outcomes and general environmental settings are listed in Table 1. As is shown, the psychological outcomes are expressed as experiencing affiliation with others, challenge, risk taking, being away from society, and other such terms. The settings are described in terms of physical resources, social situations, and managerial actions and facility.

Given these definitions, specific resource, social and managerial parameters need to be specified to determine if the opportunities can be supplied on any specific site. Brown et al. (1978) suggest that for broad spectrum classes, remoteness of areas, size of areas, permanent modifications of area, and renewable resource modifications of areas, are the critical parameters to measure to assess capability. For more definitive spectrum locations and for specific activities, additional parameters would be relevant. For suitability determinations social and managerial considerations would be brought into the analysis. After a site capability determination is made, the quantity of opportunity must be estimated. This involves determining supply coefficients for each experience opportunity and applying the coefficients to the area of supply. The general output will be which opportunities and how much of them can be supplied on each land unit (generally greater in size than an acre). Brown et al. (1978) offer some maximum supply values but indicate that much more research needs to be done on this topic.

Using the conceptual structure for relating setting characteristics to experiences as outlined above, the effects of fires on recreation opportunity supply can be estimated. The experience opportunities and their environmental conditions have been specified by Brown et al. Yet to be modeled are the effects of different input factors like changes in vegetation and wildlife populations. Also more work needs to be done on estimating capacities. In the end, however, the outlook for a functioning model looks promising.

Table 1. Experience opportunity classes and their associated physical, social, and managerial settings:

Opportunity Class	Experience Opportunity	Physical, Social, and Managerial Setting
Primitive	Opportunity for isolation from the sights and sounds of man, for a vastness of scale, to feel a part of the natural environment, to have a high degree of challenge and risk, and to use outdoor skills.	Area is characterized by essentially unmodified natural environment of fairly large size. Concentration of users is very low and evidence of other area users is minimal. The area is managed to be essentially free from evidence of man-induced restrictions and controls. Only essential facilities for resource protection are used and are constructed of on-site materials. No facilities for comfort or convenience of the user are provided. Spacing of groups is informal and dispursed to minimize contacts with other groups or individuals. Motorized use within the area is not permitted.
Semi-Primitive Non-Motorized	Some opportunity for isolation from the sights and sounds of man and a vastness of scale, but not as important as for primitive opportunities. Opportunity to have a high degree of interaction with the natural environment, to have moderate challenge and risk, and to use outdoor skills.	Area is characterized by a predominantly unmodified natural environment of moderate to large size. Concentration of users is low, but there is often evidence of other area users. The area is managed in such a way that minimum on-site controls and restrictions may be present, but are subtle. Facilities are primarily provided for the protection of resource values and safety of users. On-site materials are used where possible. Spacing of groups may be formalized to disperse use and provide low-to-moderate contacts with other groups or individuals. Motorized use is not permitted.

Table 1. (Continued)

Opportunity Class	Experience Opportunity	Physical, Social, and Managerial Setting
Semi-Primitive Motorized	Some opportunity for isolation from the sights and sounds of man and a vastness of scale, but not as important as for primitive opportunities. Opportunity to have a high degree of interaction with the natural environment, to have moderate challenge and risk, and to use outdoor skills. Explicit opportunity to use motorized equipment while in the area	Area is characterized by a predominantly unmodified natural environment of moderate to large size. Concentration of users is low, but there is often evidence of other area users. The area is managed in such a way that minimum on-site controls and restrictions may be present, but are subtle. Facilities are primarily provided for the protection of resource values and safety of users. On-site materials are used where possible. Spacing of groups may be formalized to disperse use and provide low-to-moderate contacts with other groups or individuals. Motorized use is permitted.
Intermediate	About equal opportunities for affiliation with user groups and opportunities for isolation from sights and sounds of man. opportunity to have a high degree of interaction with the natural environment. Challenge and risk opportunities are not very important. Practice and testing of outdoor skills may be important. Opportunities for both motorized and non-motorized forms of recreation are desired.	Area is characterized by predominantly natural environment with moderate evidences of the sights and sounds of man. Such evidences usually harmonize with the natural environment. Concentration of users may be low to moderate with facilities sometimes provided for group activity. Evidence of other users is prevalent. Controls and regimentation offer a sense of security and are on-site. Rustic facilities are provided for convenience of the user as well as for safety and resource protection. Moderate densities of groups is provided for in developed sites and on roads and trails. Low to moderate densities prevail away from developed sites and facilities. Renewable resource modification and utilization practices are evident, but harmonize with the natural environment. Conventional motorized use is provided for in construction standards and design of facilities.

Table 1. (Continued)

Opportunity Class	Experience Opportunity	Physical, Social, and Managerial Setting
Concentrated	Opportunities to experience affiliation with individuals and groups are prevalent as is the convenience of sites and opportunities. These factors are more important than the setting of the physical environment. Opportunities for challenge, risk taking, and outdoor skills are unimportant.	Area is characterized by substantially modified natural environment. Renewable resource modification and utilization practices are primarily to enhance specific recreation activities and to maintain vegetative cover and soil. Sights and sounds of man are readily evident, and the concentration of users is often moderate to high. A considerable number of facilities are designed for use by a large number of people. Facilities are often provided for special activities. Moderate to high densities of groups and individuals are provided for in developed sites, on roads nad trails, and water surfaces. Moderate densities are provided for away from developed sites. Facilities for intensified motorized use and parking are available.
Modern Urbanized	Opportunities to experience affiliation with individuals and groups are prevalent as is the convenience of sites and opportunities. Experiencing natural environments, having challenges and risks afforded by the natural environment, and the use of outdoor skills are relatively important.	Area is characterized by a substantially urbanized environment although the background may have natural elements. Renewable resource modification and utilization practices are to enhance specific recreation activities. Vegetative cover is often exotic and manicured. Soil protection usually accomplished with hand surfacing and terracing. Sights and sounds of man, on-site, are predominant. Large numbers of users can be expected both on-site and in nearby areas. A considerable number of facilities are designed for the use and convenience of large numbers of people and include electrical hookups and contemporary sanitation services. Controls and regimentation are obvious and numerous. Facilities are provided for special activities. Facilities for highly intensified motor use and parking are available with forms of mass transit often available to carry people throughout the site.

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